CONTRACT NAS8-31844

PHASE B-FINAL DEFINITION AND PRELIMINARY DESIGN STUDY FOR THE INITIAL ATMOSPHERIC CLOUD PHYSICS LABORATORY (ACPL) - A Spacelab Mission Payload

FINAL REVIEW (DR-MA-03)

(NASA-CR-150136) PHASE B: FINAL DEFINITION AND PRELIMINARY DESIGN STUDY FOR THE INITIAL ATMOSPHERIC CLOUD PHYSICS LABORATORY (ACPL): A SPACELAB MISSION PAYLOAD. FINAL REVIEW (DR-MA-03) (TRW Defense and Space Systems G3/16

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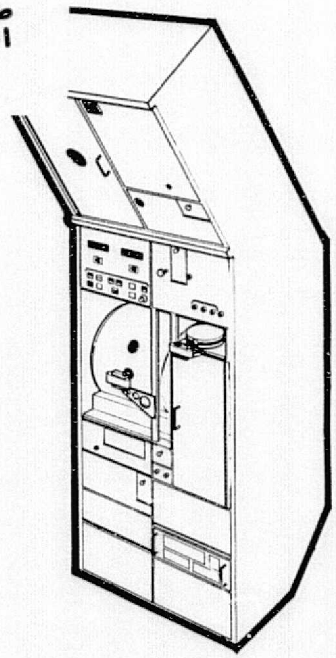

DECEMBER 7, 1976

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
Marshall Space Flight Center, Alabama 35812

By
ACPL PROGRAM TEAM
O.W. Clausen, Program Manager

TRW
DEFENSE AND SPACE SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH • CALIFORNIA 90278

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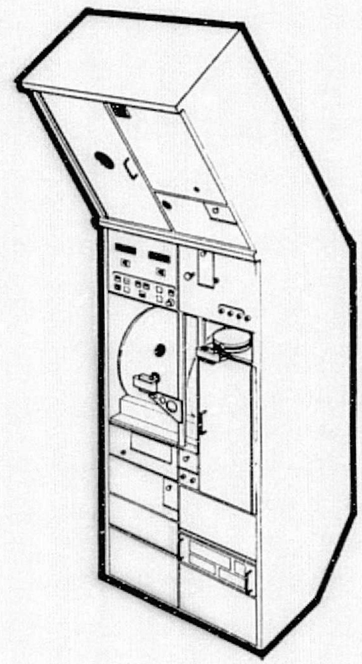

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FINAL REVIEW AGENDA

NASA REMARKS			8:30 - 8:35
I.	INTRODUCTION		8:35 - 8:45
II.	PROGRAM EXECUTIVE OVERVIEW		8:45 - 9:15
III.	SYSTEMS ENGINEERING		9:15 - 9:35
IV.	TECHNICAL DISCUSSION AND PRELIMINARY DESIGN		
	A)	EXPERIMENTAL CHAMBERS	9:35 - 10:55
	B)	SCIENTIFIC SUBSYSTEMS	10:55 - 12:00
	C)	SUPPORT SUBSYSTEMS	1:00 - 3:45
V.	SYSTEMS SUMMARY		3:45 - 4:05
VI.	ACPL PHASE B PROGRAM SUMMARY		4:05 - 4:20

TRW SYSTEMS GROUP

PROGRAM EXECUTIVE OVERVIEW

BILL CLAUSEN

TRW

The objectives established at the outset of this Phase B Study are summarized on the facing page. In addition to satisfying identified requirements, the preliminary design of the initial ACPL is also to be capable of evolving naturally over the planned 10 year, 20 mission lifetime to perform a variety of atmospheric cloud physics experiments, many of which have not been defined.

ATMOSPHERIC CLOUD PHYSICS LABORATORY

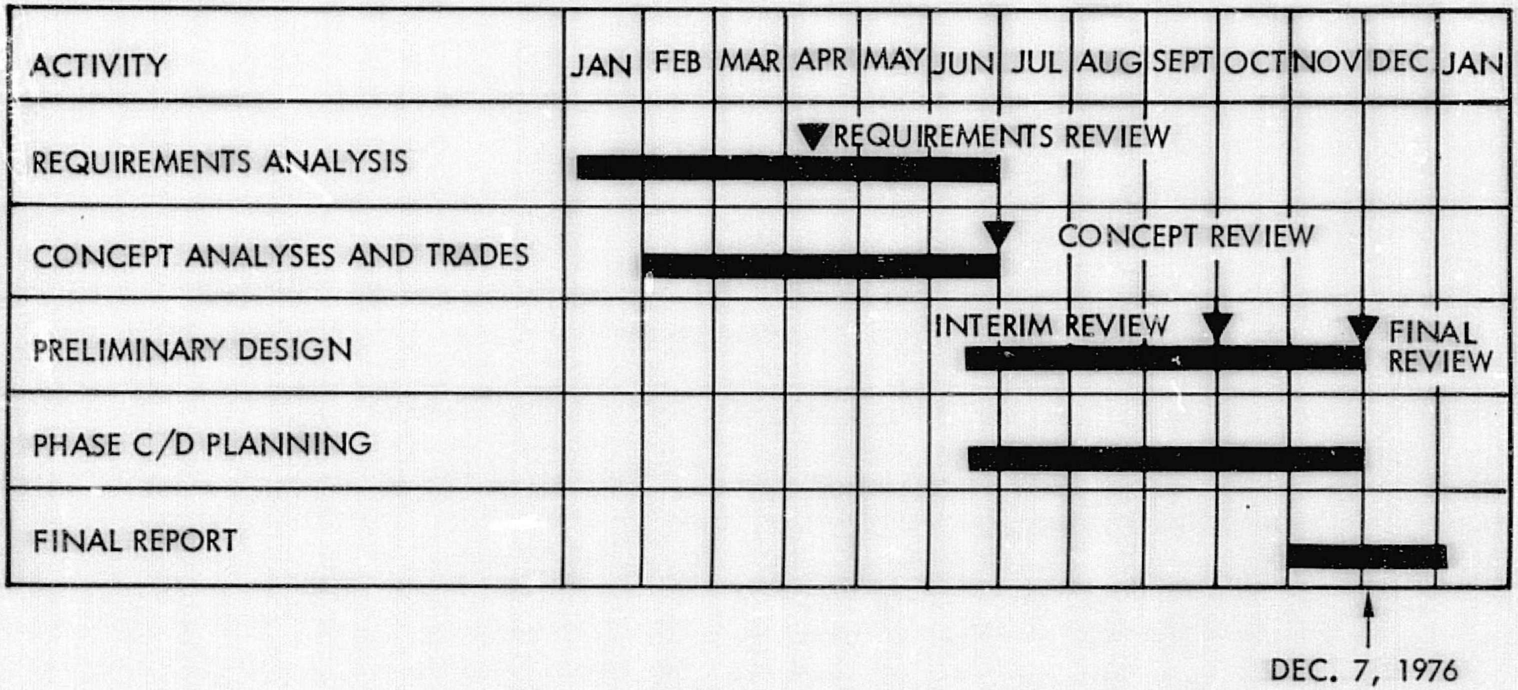
SPACELAB PAYLOAD PHASE B STUDY OBJECTIVES

- PROVIDE FINAL DEFINITION AND PRELIMINARY DESIGN OF AN INITIAL ACPL FOR FUNDAMENTAL STUDIES OF ATMOSPHERIC CLOUD MICROPHYSICAL PROCESSES IN ZERO GRAVITY.
- PREPARE PRELIMINARY PLANNING FOR DETAILED DESIGN, DEVELOPMENT, FABRICATION, TEST AND OPERATION OF THE INITIAL ACPL.
- DEVELOP REALISTIC COST ESTIMATES FOR PHASE C/D.

TRW
SYSTEMS GROUP

The Phase B Study schedule is shown on the facing page. Following selection of the basic ACPL concept at the Concept Review, the effort has focused on preliminary design of the laboratory, and on definition and planning of a Phase C/D hardware program. Delivery of the Final Report is scheduled for 9 January 1977.

ACPL PROGRAM SCHEDULE



TRW

In keeping with the study objectives and with the groundrules being developed by NASA for implementation of a low cost Spacelab payload, the basic design philosophy shown on the facing page was established to guide the preliminary design effort. Principal among these elements was that the proposed laboratory design be based on well thought out, proven engineering approaches that;

- would minimize technical risk (and development costs),
- could make maximum use of commercially available hardware, and
- would permit realistic planning and costing of the Phase C/D program.

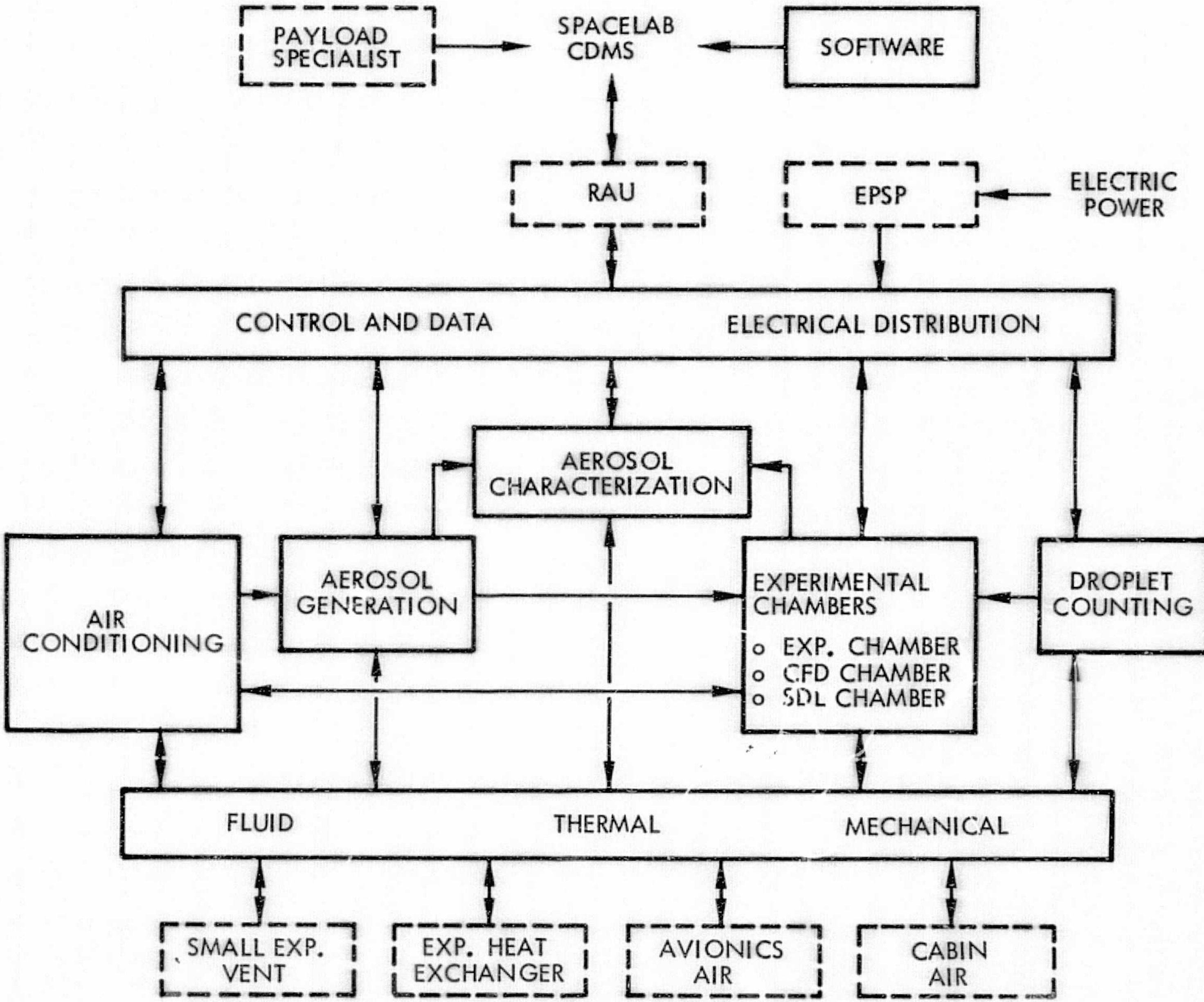
ACPL PRELIMINARY DESIGN PHILOSOPHY

- UNDERSTAND BASIS, INTERRELATIONSHIPS OF IMPOSED SCIENCE REQUIREMENTS
- MAXIMIZE PRACTICAL USE OF RELEVANT GROUND-BASED LABORATORY EXPERIENCE
- USE SIMPLE, PROVEN, CONSERVATIVE DESIGN APPROACHES; MINIMIZE DEVELOPMENT RISKS
- MAXIMIZE USE OF COMMERCIALLY AVAILABLE HARDWARE
- MAXIMIZE EFFICIENT USE OF AVAILABLE SPACELAB RESOURCES
- IN-DEPTH TECHNICAL REVIEW OF EACH PROPOSED SYSTEM, SUBSYSTEM DESIGN APPROACH
- MAXIMIZE MSFC, SCIENCE INVOLVEMENT IN DESIGN EFFORT
- EARLY ATTENTION TO IMPACT OF FABRICATION, INTEGRATION AND TEST

TRW SYSTEMS GROUP

This ACPL system block diagram illustrates the functional elements required to prepare samples for and to observe the cloud processes occuring in the three experimental chambers (Expansion Chamber, Continuous Flow Diffusion Chamber, Static Diffusion Liquid Chamber). Also shown are the support elements (i.e., fluid, thermal, mechanical, control & data, electrical distribution) which form the primary interfaces with Spacelab; chief among these interfaces is the Spacelab Command and Data Management System (CDMS).

ACPL SYSTEM BLOCK DIAGRAM



TRW

ATMOSPHERIC CLOUD PHYSICS LABORATORY
SUBSYSTEMS

<u>EXPERIMENTAL CHAMBERS</u>

- EXPANSION CHAMBER
- CONTINUOUS FLOW DIFFUSION (CFD) CHAMBER
- STATIC DIFFUSION LIQUID (SDL) CHAMBER

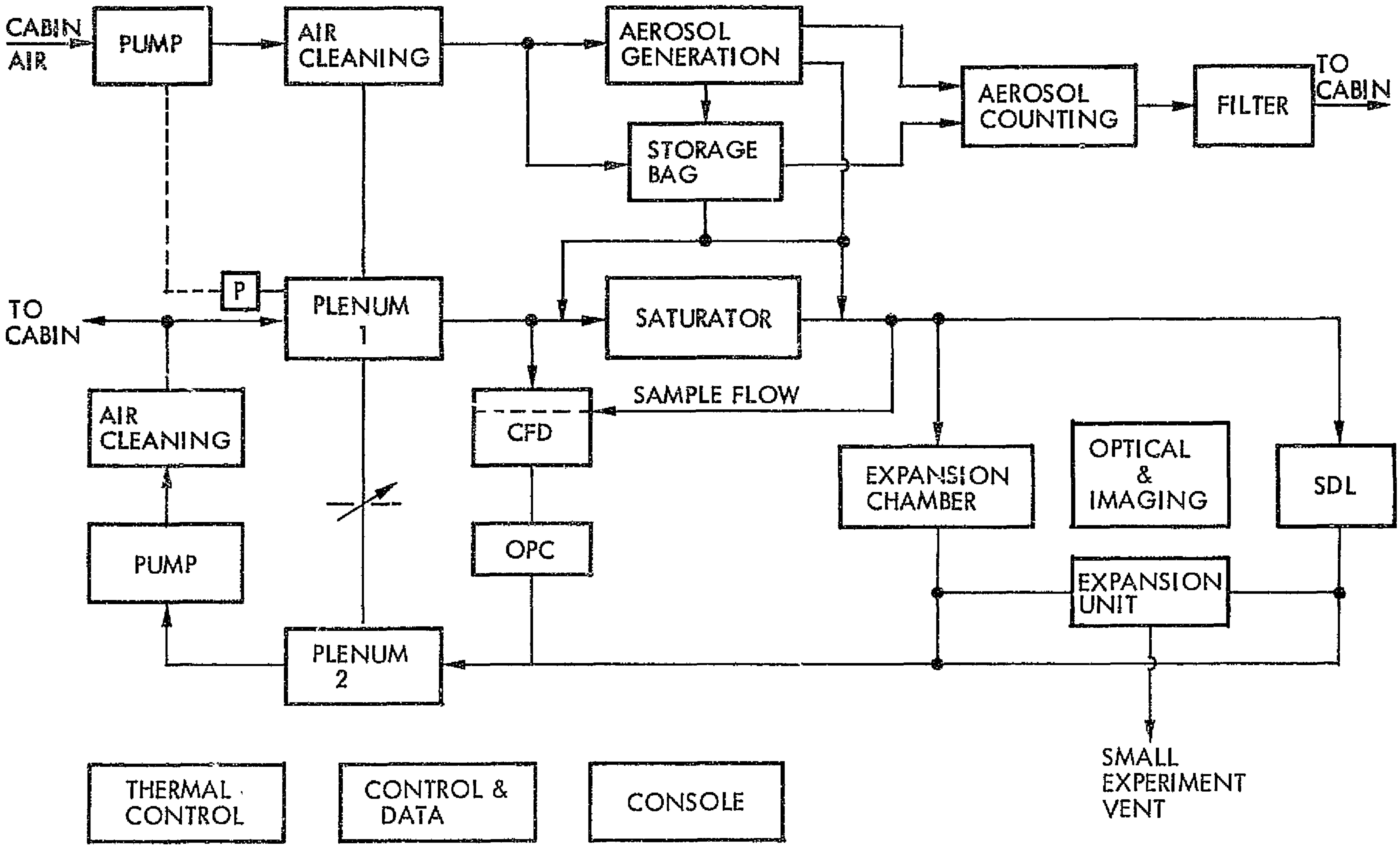
<u>SCIENTIFIC SUBSYSTEMS</u>

- AEROSOL GENERATION
- AEROSOL COUNTING
- OPTICAL AND IMAGING

<u>SUPPORT SUBSYSTEMS</u>

- FLUID SYSTEM
- AIR CLEANING
- THERMAL CONTROL
- CONTROL AND DATA
- CONSOLE

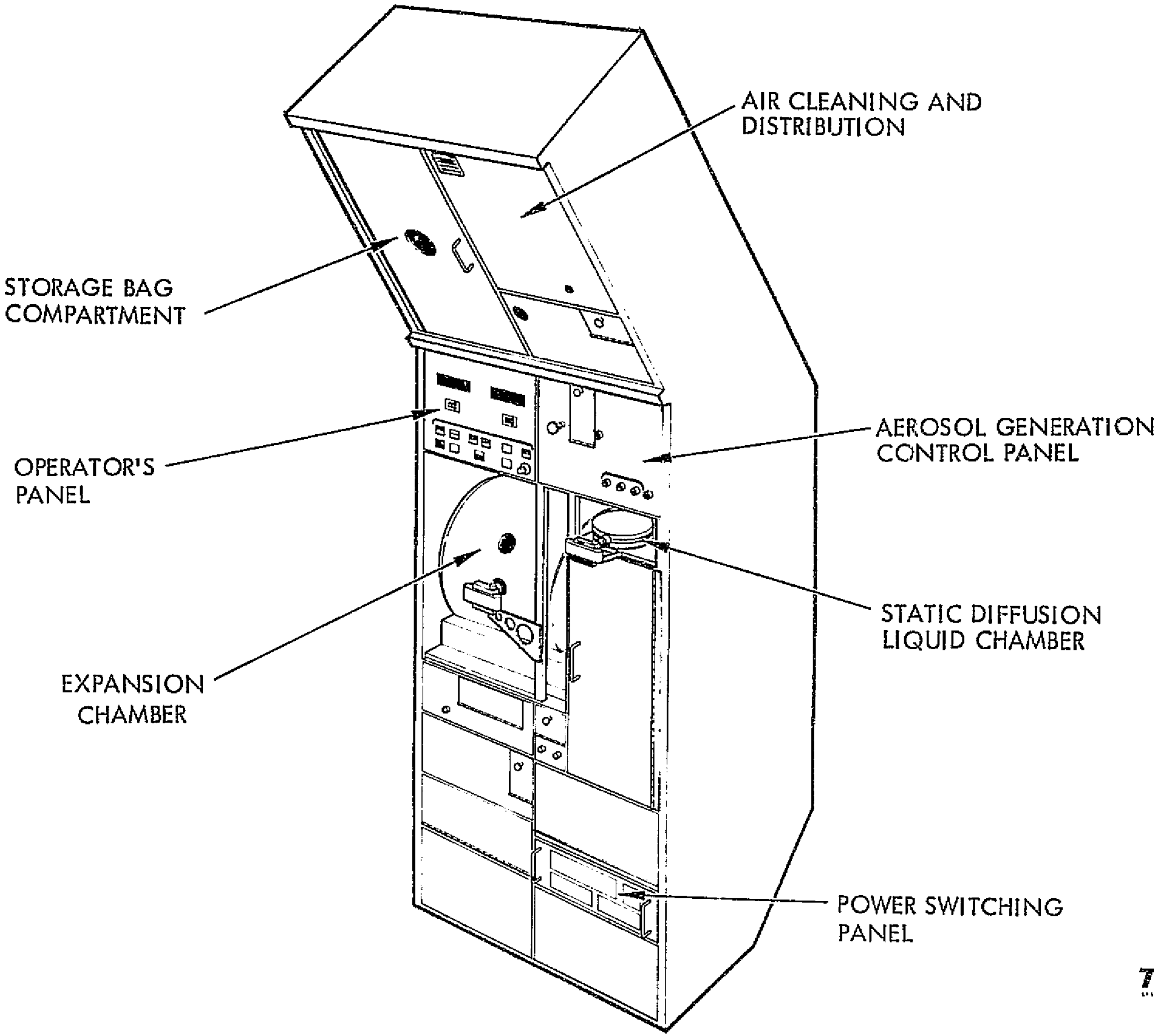
ACPL FLUID SYSTEM BLOCK DIAGRAM



TRW

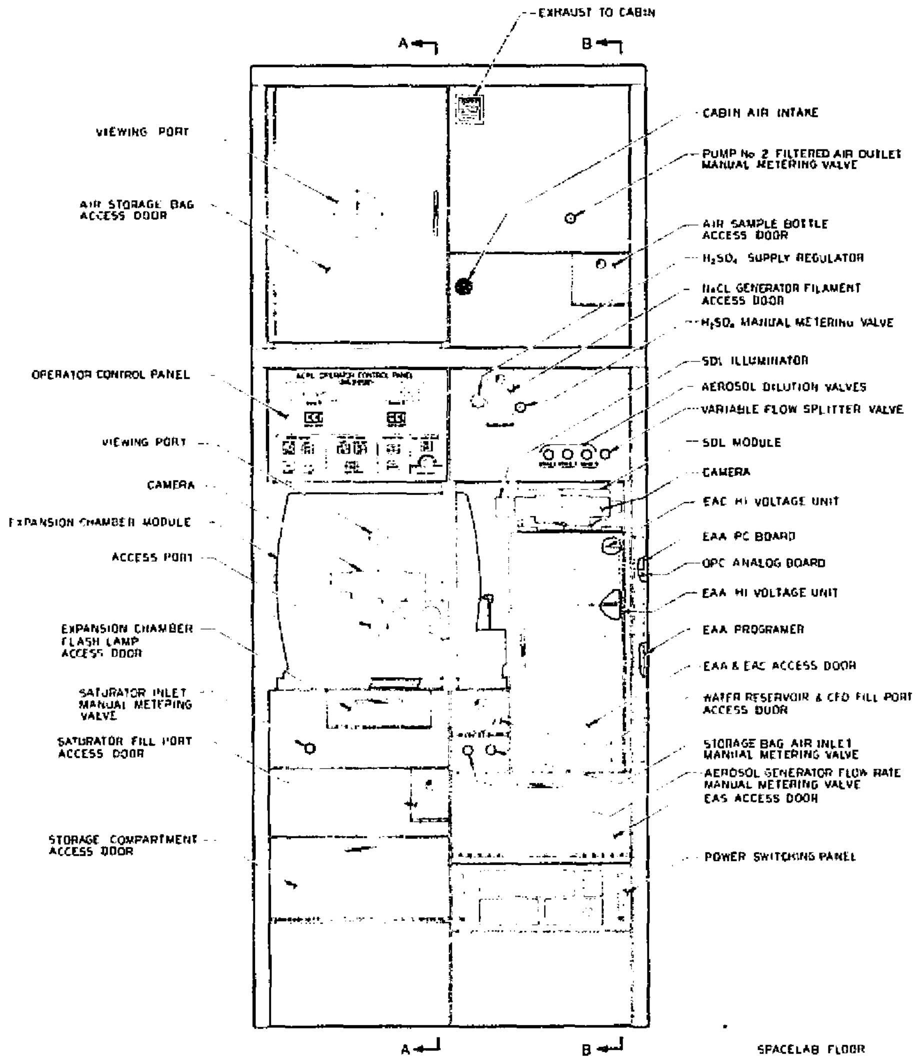
The facing page shows an isometric view of the completed ACPL preliminary design packaged in a Spacelab standard double rack.

ATMOSPHERIC CLOUD PHYSICS LABORATORY



The packaging layout on the facing page shows the relative locations of the major ACPL equipment.

ACPL PACKAGING LAYOUT



FRONT PANEL VIEW
(UPPER BACK SECTION ROTATED INTO PLANE OF PAPER)

TRW
SYSTEMS GROUP

The ACPL preliminary design resulting from this Phase B Study emphasizes proven, well thought out engineering approaches to the science requirements in the Level I Specifications. A few of the key technical features of this design are shown on the facing page; many more are described as part of the discussion of the individual subsystems.

KEY TECHNICAL FEATURES
ACPL PRELIMINARY DESIGN

- FLUID SUBSYSTEM ACHIEVES REQUIRED PRESSURE AND FLOW CONTROL WITH MINIMUM ACTIVE ELEMENTS. NO ACTIVE CONTROL ELEMENTS OR SENSORS IN EXPERIMENTAL AEROSOL LINES.
- THERMAL CONTROL SUBSYSTEM USES CONVENTIONAL PUMPED FLUID LOOP CONCEPT TO MINIMIZE DEVELOPMENT RISK. APPROACH ASSURES EQUIVALENT GROUND-BASED AND ZERO G PERFORMANCE; ALLOWS CFD VERTICAL OPERATION ON THE GROUND.
- COMMON THERMOELECTRIC COOLER DESIGN MAXIMIZES OPERATING EFFICIENCY, MINIMIZES COST. SYSTEM CONCEPT ALLOWS FOR IN-SITU TEMPERATURE DIFFERENCE CALIBRATION IN CFD.
- EXPANSION CHAMBER THERMAL APPROACH ALLOWS FLUSHING, FILLING AND THERMAL STABILIZATION WITHOUT WALL TEMPERATURE GRADIENTS; SMALL OPERATING TEMPERATURE DIFFERENCES MINIMIZE SENSOR ERRORS.
- PACKAGING CONCEPT MODULARIZED FOR EASE OF INTEGRATION, MAINTENANCE, EVOLUTIONARY GROWTH. SYSTEM DESIGN MAXIMIZES APPLICATION OF COMMERCIALLY AVAILABLE EQUIPMENT.
- 150 LITER STORAGE BAG INCLUDED TO ACCOMMODATE GENERATOR INSTABILITIES, PERMITS TIMELINED DILUTIONS, ALLOWS MIXING OF AEROSOLS, ETC. HIGH SYSTEM FLOW IN AEROSOL LINES MINIMIZES LOSSES.
- NOVEL PERFUSION CONCEPT TO MINIMIZE CFD SAMPLE INLET LOSSES.

TRW

As mentioned previously, TRW's preliminary design emphasizes use of proven, commercially available hardware in order to minimize development msk and program cost. The table on the facing page, compiled from the ACPL Master Equipment List, illustrates this point. The three government furnished items are Spacelab Double Rack, Remote Acquisition Unit, and Electrical Power Switching Panel.

MAJOR EQUIPMENT LIST SUMMARY

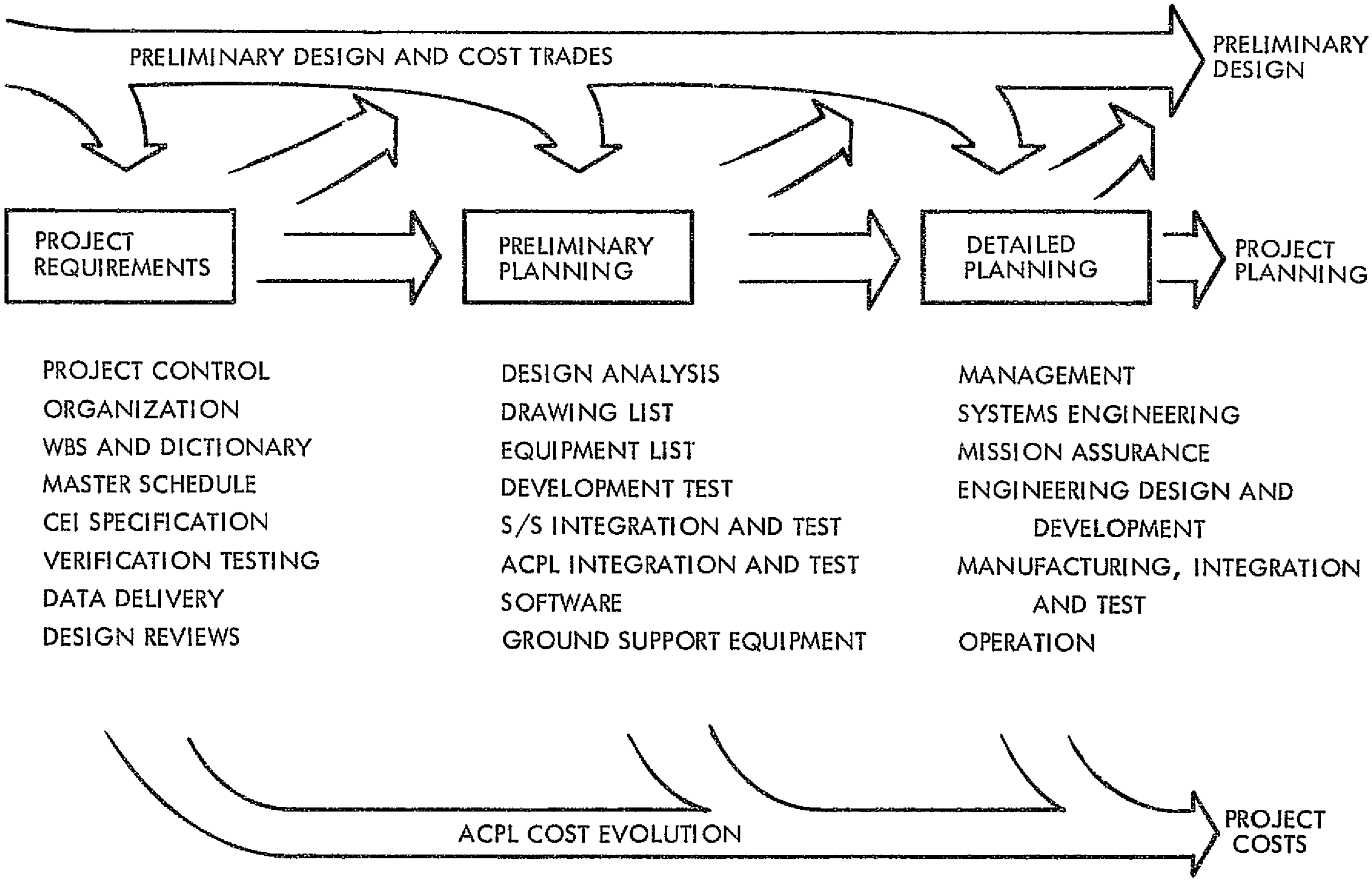
SUBSYSTEM	TOTAL ITEMS	FABRICATE ITEMS	COMMERCIALLY AVAILABLE *	GFE
FLUID	24	4	20	0
AIRCLEANING	9	0	9	0
AEROSOL GENERATOR	11	3	8	0
AEROSOL COUNTING	4	0	4	0
CFD CHAMBER	8	8	0	0
EXPANSION CHAMBER	25	18	7	0
SDL CHAMBER	12	12	0	0
THERMAL CONTROL	15	0	15	0
CONTROL & DATA	17	4	12	1
OPTICAL & IMAGING	14	2	12	0
CONSOLE	22	5	15	2
TOTAL	161	56 (35%)	102 (63%)	3 (2%)

* MANUFACTURER & MODEL NUMBER IDENTIFIED FOR ALL

TRW SYSTEMS GROUP

Programmatic planning for the ACPL Phase C/D (hardware) effort was another major activity during the last half of this Phase B Study. Evolving in stages, as the preliminary design definition progressed, this planning provided the basis for development of Phase C/D cost estimates. Planning outputs (and resulting cost estimates) also influenced the preliminary design effort by providing alternatives to minimize total program costs.

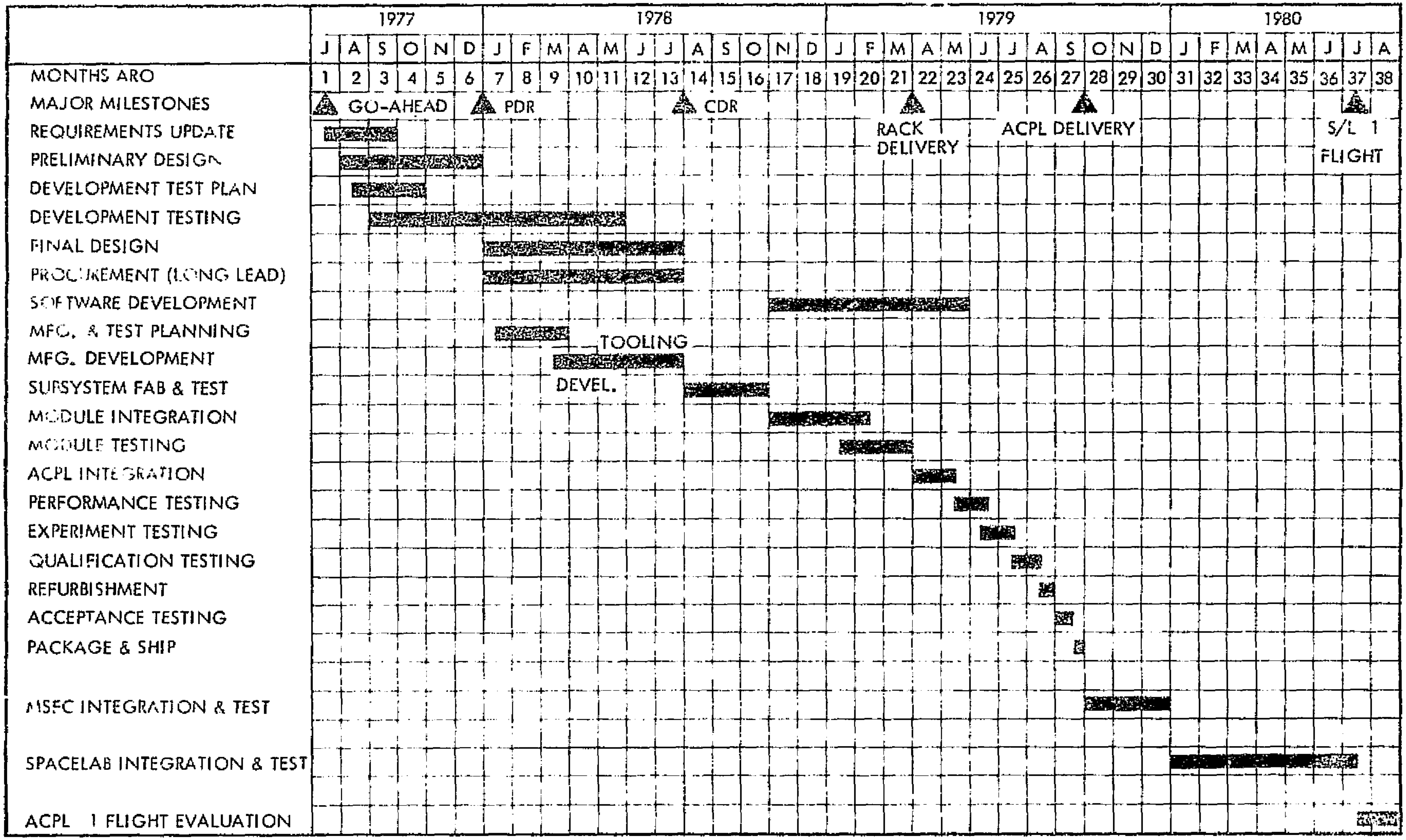
PHASE C/D PROGRAM PLANNING



A master schedule for accomplishing the ACPL Phase C/D program is shown on the facing page. Key dates include the following:

Preliminary Design Review	:	31 Dec. 1977
Critical Design Review	:	1 Sept. 1978
Rack Delivery (to TRW)	:	1 April 1979
Software Completion	:	1 June 1979
ACPL Delivery (to MSFC)	:	1 Oct. 1979
Spacelab #1 Flight	:	Mid 1980

ACPL PHASE C/D MASTER SCHEDULE



There are many difficult technical and programmatic challenges to be met in the design, fabrication, test and operation of the initial ACPL. TRW, in the performance of this Phase B Study, has attempted to identify as many of these challenges as possible and to find realistic, cost effective solutions to meet the requirements. The facing page lists what we feel are the major accomplishments to come from the study; more detail is provided in the following discussion.

ATMOSPHERIC CLOUD PHYSICS LABORATORY

PRELIMINARY DESIGN STUDY ACCOMPLISHMENTS

- AIDED IN ESTABLISHING, PRIORITIZING REALISTIC SET OF SCIENTIFIC REQUIREMENTS FOR THE INITIAL ACPL.
- IDENTIFIED AND WORKED MANY KEY TECHNICAL PROBLEMS ASSOCIATED WITH MEETING THESE REQUIREMENTS.
- PROVIDED DETAILED TECHNICAL DEFINITION OF INITIAL ACPL INCLUDING IDENTIFICATION OF COMMERCIALLY AVAILABLE COMPONENTS AND REALISTIC INTERFACES WITH SPACELAB.
- DEFINED OPERATIONAL REQUIREMENTS FOR ACPL DURING INTEGRATION WITH SPACELAB AND DURING THE INITIAL MISSION.
- DEFINED REALISTIC PHASE C/D PROGRAM REQUIREMENTS FOR FABRICATION AND OPERATION OF THE INITIAL ACPL. DEVELOPED A PLAN FOR ACCOMPLISHING THESE REQUIREMENTS.

TRW

SYSTEMS ENGINEERING

RALPH SCHILLING

Some of the key activities of System Engineering on ACPL are listed here. System Engineering was divided into two phases, with the major effort contributing to concept selection during the first half of the Phase B study.

ACPL SYSTEM ENGINEERING

- MAJOR ACTIVITIES SUPPORTED CONCEPT SELECTION
  - ESTABLISHED PERFORMANCE REQUIREMENTS
  - DEFINED SPACELAB INTERFACES
  - DEFINED INTERNAL INTERFACES
  - ESTABLISHED RESOURCE BUDGETS
  - PERFORMED ANALYSES AND TRADE STUDIES
- CONTINUING ACTIVITIES SUPPORTED PRELIMINARY DESIGN
  - EVALUATED MAJOR OPTIONS
  - PREPARED SPECIFICATIONS AND ICD'S
  - DEVELOPED OPERATION TIMELINES
  - PERFORMED SYSTEM EVALUATIONS

TRW

The various interfaces between the ACPL and Spacelab are identified here. The major interfaces involve the four ACPL support subsystems: Fluid, Thermal Control, Control and Data, and Console. The specific details of these interfaces are presented as part of the discussion of these individual subsystems.

SPACELAB INTERFACES

- STRUCTURE - STANDARD DOUBLE RACK
- ELECTRIC POWER DISTRIBUTION - EXPERIMENT POWER SWITCHING PANEL
- ENVIRONMENTAL CONTROL
  - CABIN ATMOSPHERE
  - CABIN AIR LOOP
  - AVIONICS AIR LOOP
  - EXPERIMENT HEAT EXCHANGER
  - SMALL EXPERIMENT VENT
- COMMAND AND DATA MANAGEMENT
  - REMOTE ACQUISITION UNIT
  - EXPERIMENT COMPUTER
  - DATA DISPLAY UNIT AND KEYBOARD
- SOFTWARE - EXPERIMENT COMPUTER OPERATING SYSTEM
- COMMON PAYLOAD SUPPORT EQUIPMENT - FILM VAULT

The ACPL has been packaged in a standard double rack. In addition to accommodating the baseline equipment for the first flight, specific provision has been made to accommodate growth items, including a self-contained computer for control of the ACPL.

ACPL RESOURCE REQUIREMENTS

VOLUME

- ACPL HAS BEEN PACKAGED IN STANDARD DOUBLE RACK
  - INCLUDES 50 LITER STORAGE COMPARTMENT
- SPECIFIC PROVISION TO ACCOMMODATE GROWTH ITEMS
  - CONDENSATION NUCLEUS COUNTER
  - DIFFUSION BATTERY
  - THIRD AEROSOL GENERATOR
- PRESENT PACKAGING DESIGN WILL ACCOMMODATE SELF-CONTAINED COMPUTER

TRW

The total mass of the ACPL is substantially below the 575-kg load limit for a double rack and, hence, a substantial contingency exists for this resource.

ACPL RESOURCE REQUIREMENTS

MASS (KG)

FLUID	112
AIR CLEANING	10
AEROSOL GENERATOR	17
AEROSOL COUNTER	44
CONTINUOUS FLOW DIFFUSION CHAMBER	19
EXPANSION CHAMBER	21
STATIC DIFFUSION LIQUID CHAMBER	9
THERMAL CONTROL	55
CONTROL AND DATA	81
OPTICAL AND IMAGING	8
CONSOLE	57
TOTAL	433

TRW

In order to determine the practicality of using thermoelectric coolers for the expansion chamber, detailed optimization of cooler configuration was carried out to minimize the electrical peak power and energy requirements.

OPTIMIZATION OF EXPANSION CHAMBER THERMOELECTRIC POWER CONSUMPTION

- THERMOELECTRIC COOLERS (TEC) ARE DOMINANT PEAK POWER LOAD
- TWO FACTORS WERE CONSIDERED IN OPTIMIZATION PROCESS
  - TEC COEFFICIENT OF PERFORMANCE - MAXIMUM FOR A SPECIFIC REFRIGERATION LOAD PER TEC UNIT
  - POWER SUPPLY EFFICIENCY - MAXIMUM FOR MAXIMUM ELECTRICAL LOAD
- USE OF THREE IDENTICAL COOLER MODULES INCORPORATING 24 TEC UNITS EACH PROVIDES SIGNIFICANT PEAK POWER REDUCTION AND TOTAL ENERGY SAVING

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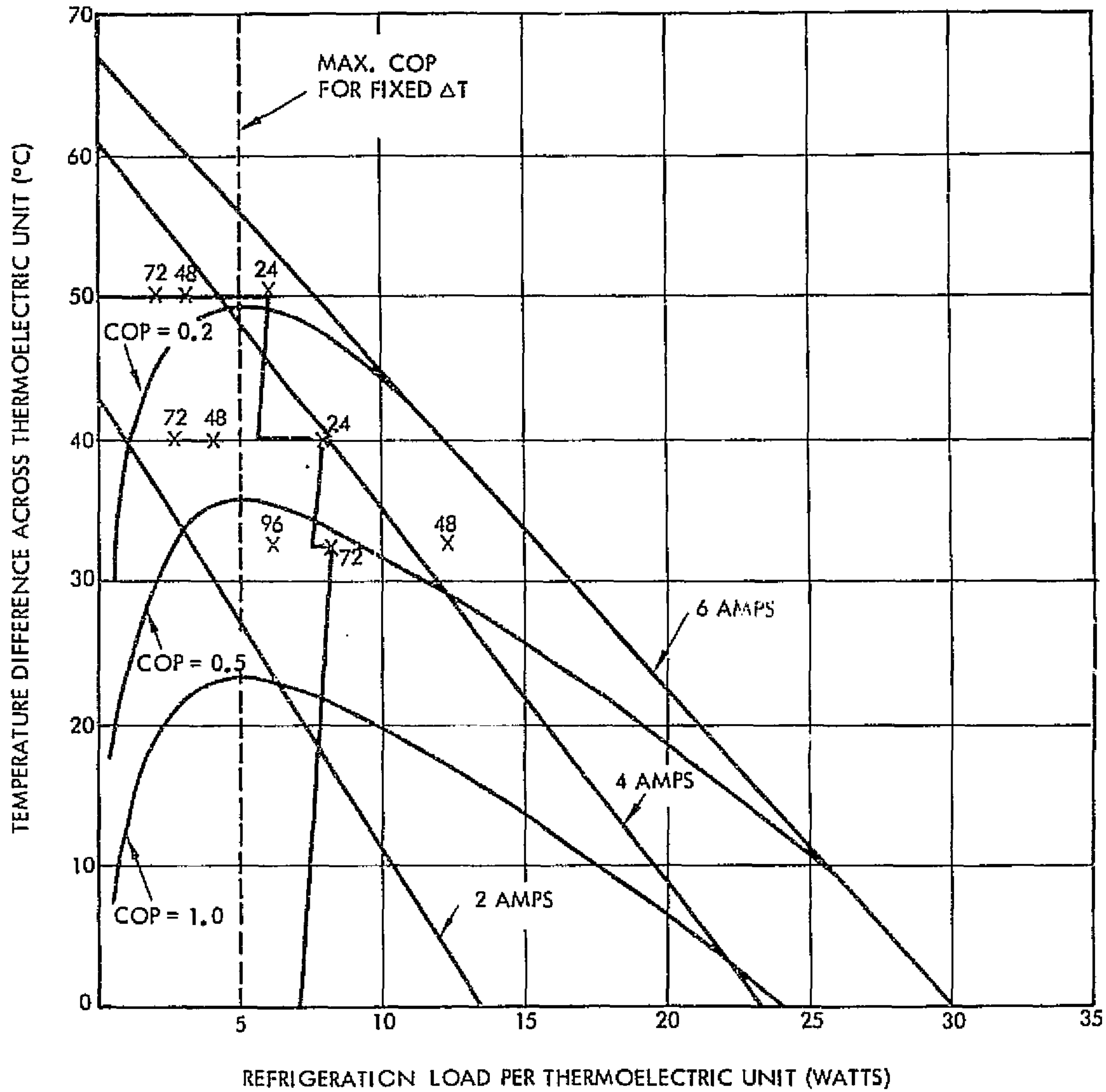
The characteristic curves give the coefficient of performance (COP) and the electric current consumption of the thermoelectric units as a function of the refrigeration load and the temperature difference across the unit. The points designated by x and a number between 24 and 96 indicate specific worst-case operating conditions as a function of number of thermoelectric units used.
The stepped line beginning horizontally at ΔT = 50 °C is the operating envelope chosen to minimize the peak power and energy requirements.

THERMOELECTRIC CHARACTERISTIC CURVES



TRW

The power consumptions corresponding to the worst-case operating points indicated by x in the preceding graph are tabulated here. The peak power for 6 °C per minute cooling rates is clearly minimized by using a large number of thermoelectric units ($\sim$ 72) while the power consumption for 0.5 °C per minute cooling rates is clearly minimized by using a much smaller number of units ($\sim$ 24). This consideration led to the choice of three cooler modules of 24 units each. These modules can be switched in and out of the expansion chamber thermal control loop according to the operating conditions required.

SENSITIVITY OF POWER CONSUMPTION AS FUNCTION OF NUMBER OF TEC UNITS

COOLING RATE °C PER MIN.	WALL TEMPERATURE °C	NO. OF TEM'S	POWER CONSUMPTION (WATTS)
6	0	96	1337
6	0	72	1366
6	0	48	1761
1.2	-15	72	870
1.2	-15	48	733
1.2	-15	24	708
0.5	-25	72	1404
0.5	-25	48	1148
0.5	-25	24	1051

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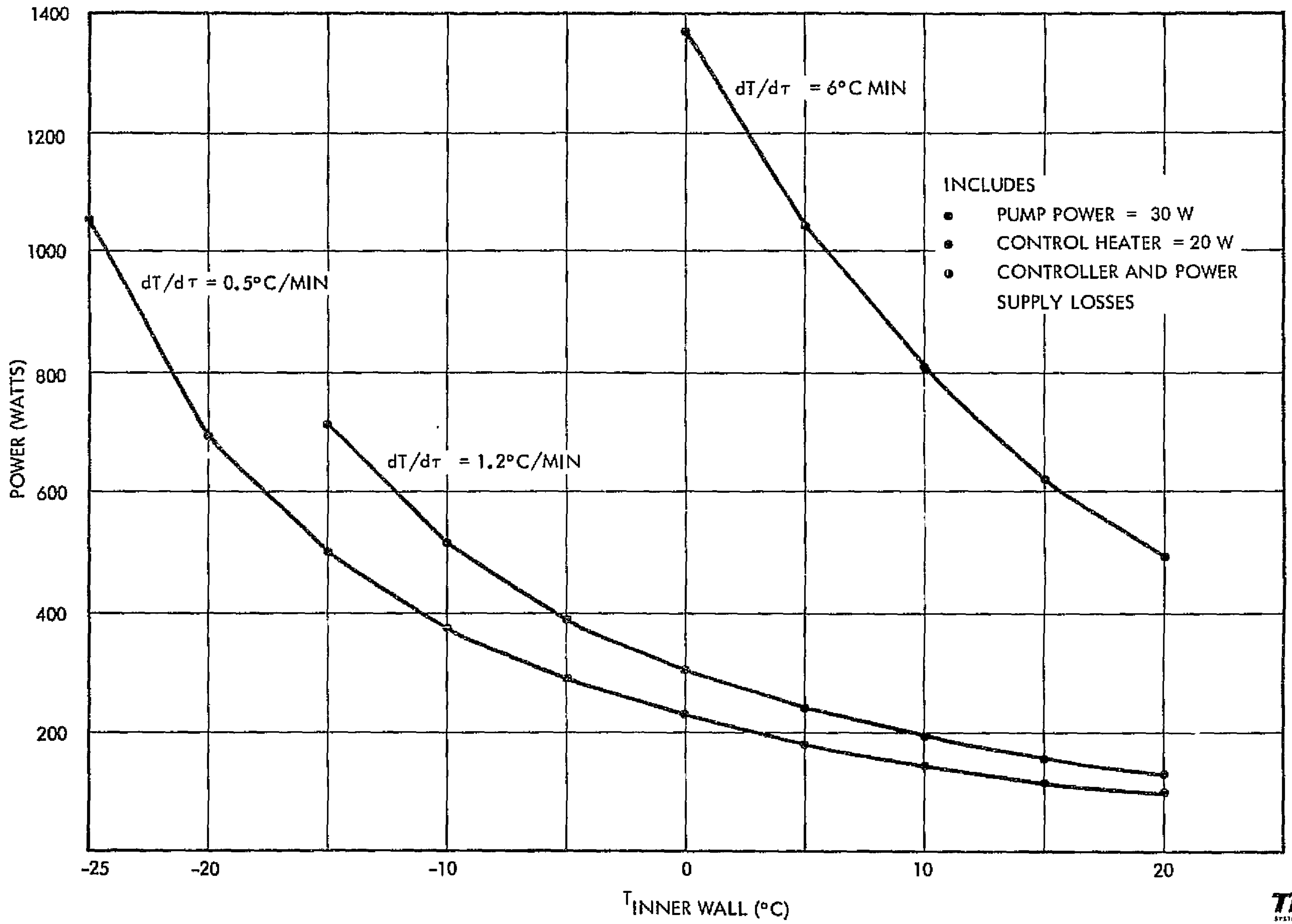
The power consumption, as a function of expansion chamber operating temperature for three cooling rates, is summarized in this graph. Although large peak power requirements exist under some conditions, these only occur at the extremes of the operating envelope. For example, by raising the lowest operating temperature by 5 °C for 6 °C per minute cooling rates, the worst-case power consumption can be reduced by over 300 watts.

EXPANSION CHAMBER ELECTRICAL POWER REQUIREMENT USING THERMOELECTRIC COOLERS



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The baseline power of 720 watts is the minimum requirement for full operation of the ACPL with the exception of the expansion chamber subsystem. All other average power requirements shown in the table are in addition to the baseline 720 watts when the designated activity is under way. The peak power requirements in each case include the average power requirement shown. Thus, the worst-case peak power required for ACPL is 720 + 1570 = 2290 watts to cool the expansion chamber at 6 °C per minute for operating temperatures near 0 °C.

ACPL RESOURCE REQUIREMENTS

ELECTRICAL POWER (WATTS)

ACTIVITY	AVERAGE POWER	PEAK POWER
ACPL BASELINE	720	
GENERATE AEROSOL	20	
ANALYZE AEROSOL	105	
OPERATE CFD CHAMBER	105	450
OPERATE SDL CHAMBER	50	410
OPERATE EXPANSION CHAMBER	165	1570

TRW

TECHNICAL DISCUSSION AND PRELIMINARY DESIGN

BRUCE MARCUS
GARY ROSIAK
RALPH SCHILLING

TRW
SYSTEMS GROUP

EXPERIMENTAL CHAMBER SUBSYSTEMS

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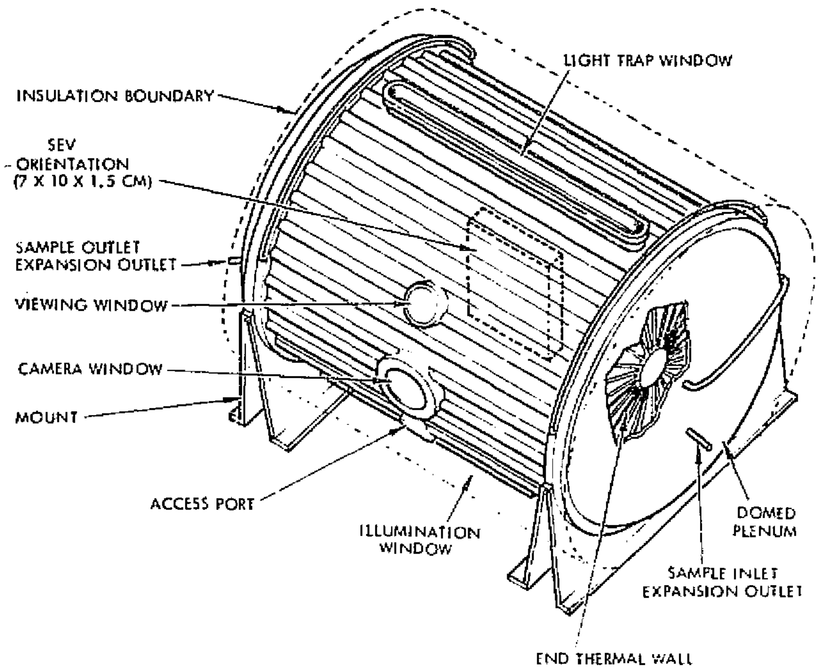
TRW

EXPANSION CHAMBER SUBSYSTEM

The facing page shows a schematic view of the Expansion Chamber and a list of key features to look for in the discussion to follow.

EXPANSION CHAMBER SUBSYSTEM



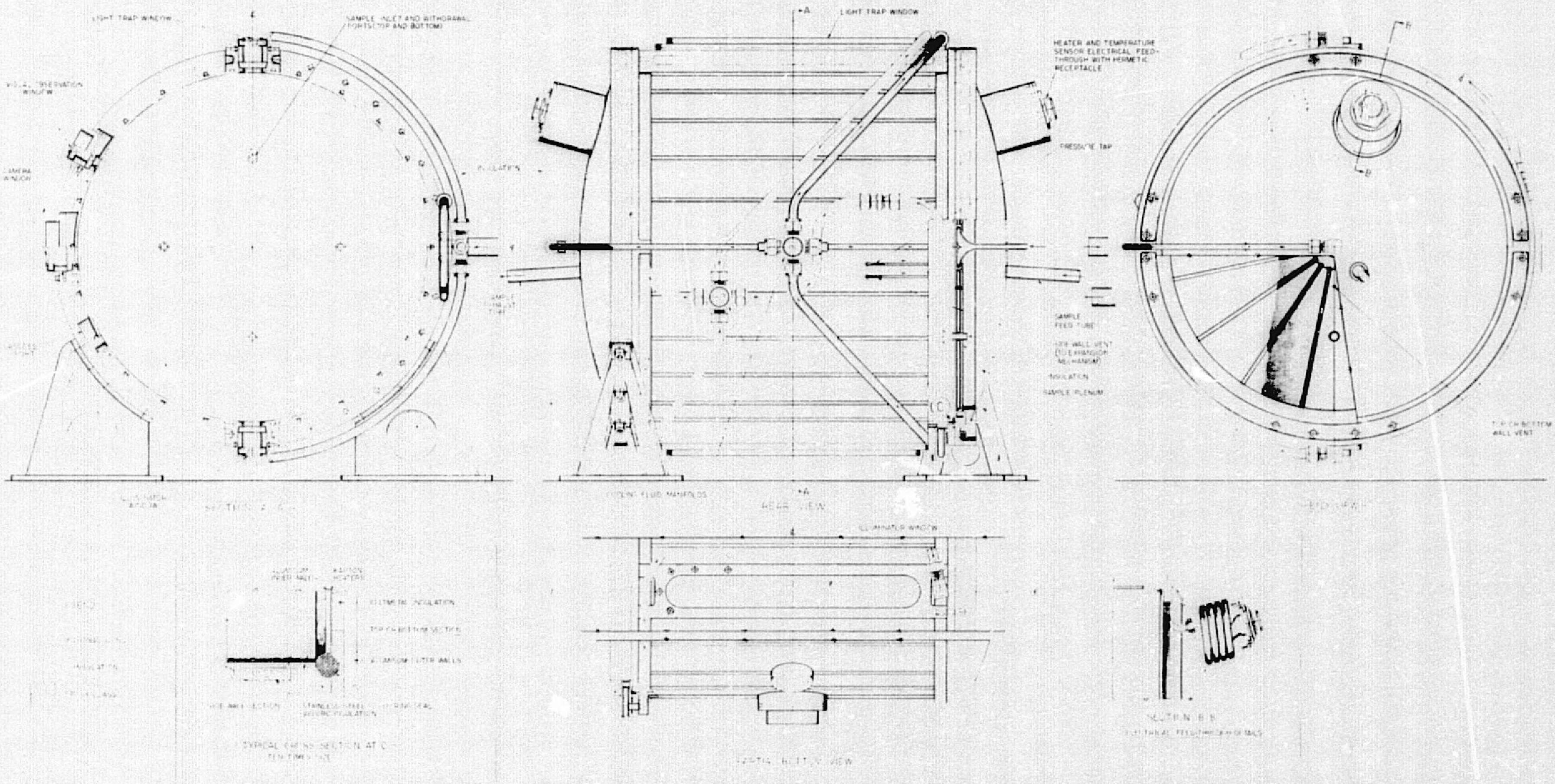
FEATURES

- THERMAL CONTROL
  - DOUBLE WALL SEPARATED BY INSULATION
  - OUTER WALL COOLED BY TEC, PUMPED FLUID LOOPS
  - LIGHT INNER WALL CONTROLLED BY ZONED TRIMMER HEATERS
- AEROSOL AND GAS PROCESSES
  - FLUSHING THROUGH DOMED PLENUMS AT ZERO ΔT CONDITIONS
  - FOUR INLET/OUTLET HOLES EACH END
  - EXPANSION THROUGH FLUSHING HOLES
  - INNER WALL SEALED TO MINIMIZE DISTURBANCES
- OPTICS AND IMAGING INTERFACE
  - ILLUMINATION AND CAMERA WINDOWS IN CYLINDRICAL WALLS
  - LIGHT TRAP WINDOW MINIMIZES HEATING DUE TO ILLUMINATOR, ALSO REDUCES FILM FOGGING
  - SEV (7 X 10 X 1.5 CM) ORIENTED AS SHOWN
- MECHANICAL DESIGN
  - CYLINDRICAL SIDES MINIMIZE THERMAL MASS
  - DOMED PLENUMS TAKE PRESSURE DIFFERENTIAL
  - END THERMAL WALL HAS LOW THERMAL MASS
  - MOUNTED BY RIGID END FLANGES

A preliminary design layout of the Expansion Chamber is shown on the facing page. This design has been carried to a level sufficient to assure it will function properly and to assess costs.

A preliminary design layout of the Expansion Chamber is shown on the facing page. This design has been carried to a level sufficient to assure it will function properly and to as.ess costs.

EXPANSION CHAMBER SUBSYSTEM
PRELIMINARY DESIGN LAYOUT



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SYSTEMS GROUP

The major elements considered in the design of the Expansion Chamber included thermal control, aerosol and gas processes, optical interface requirements and mechanical features. Each of these will be discussed in some detail.

EXPANSION CHAMBER SUBSYSTEM

DESIGN ELEMENTS

- THERMAL CONTROL
- AEROSOL AND GAS PROCESSES
- OPTICAL INTERFACE
- MECHANICAL DESIGN

TRW

The next three pages summarize the thermal control performance.

In order to meet a requirement for expansion chamber SEV uniformity of $\pm 0.005^{\circ}C$ at cooling rates up to $6^{\circ}C/min$ (discussed later), it is necessary to control the mean wall temperature to $\pm 0.1^{\circ}C$ at this higher cooling rate as well as the $3^{\circ}C/min$ rate specified.

The low mass heater and inner wall render cooling rate changes almost instantaneous, regardless of the sign of the change. The requirement for change in $\dot{T}$ from one value to another before the mean wall temperature varies by $0.5^{\circ}C$ is exceeded with considerable margin.

Only about 2% of the expansion chamber wall area is occupied by windows or ports. Almost all of the remaining 98% will satisfy the $\pm 0.1^{\circ}C$ uniformity requirement for cooling rates of $3^{\circ}C/minute$ or less.

EXPANSION CHAMBER SUBSYSTEM

THERMAL CONTROL PERFORMANCE SUMMARY

- MEAN WALL TEMPERATURE CONTROL

<table>
<tr><th>REQUIREMENTS</th><th>PERFORMANCE</th></tr>
<tr><td>RANGE OF $\dot{T}$:
<table>
<tr><td>$\dot{T}$ (°C/MIN)</td><td>-0.5</td><td>-1.2</td><td>-6</td></tr>
<tr><td>TIME (MIN)</td><td>60</td><td>30</td><td>1</td></tr>
<tr><td>TEMP RANGE (°C)</td><td>20
TO
-20</td><td>20
TO
-15</td><td>20
TO
0</td></tr>
</table></td><td>DESIGN COMPLIES</td></tr>
<tr><td>CONTROL OF T: ±0.1 °C FOR $T \geq -3$°C/MIN</td><td>±0.1 °C FOR $\dot{T} \geq -6$°C/MIN</td></tr>
<tr><td>RATE OF CHANGE OF $\dot{T}$: CHANGE $\dot{T}$ FROM ONE VALUE TO ANOTHER WITHIN OPERATIONAL RANGE BEFORE T VARIES BY MORE THAN 0.5°C</td><td>DESIGN COMPLIES
ESSENTIALLY INSTANTANEOUS
SLOPE CHANGE</td></tr>
</table>

- WALL UNIFORMITY

REQUIREMENTS	REQUIREMENT SATISFACTION
90 PERCENT OR MORE OF CHAMBERS INTERIOR SURFACE, IS WITHIN ±0.1°C OF MEAN WALL TEMPERATURE FOR $\dot{T} \geq -3$°C/MIN	DESIGN COMPLIES

TRW

Knowing the SEV temperature (through wall temperature measurements) to $\pm 0.05^{\circ}C$ during steady state operation, and controlling the mean chamber wall temperature to $\pm 0.1^{\circ}C$ may require periodic recalibration of the thermistors in the expansion chamber walls as well as electronic components. This is necessary to reduce drift errors over the 10-year lifetime of the ACPL.

EXPANSION CHAMBER SUBSYSTEM

THERMAL CONTROL PERFORMANCE SUMMARY (CON'T)

- SEV TEMPERATURE CONTROL

REQUIREMENTS	PERFORMANCE
STEADY STATE (CONSTANT SET POINT): SEV TEMPERATURE SETABLE TO WITHIN $\pm 0.1°C$ FOR $0.5°C \le T \le 20°C$	DESIGN COMPLIES
SEV TEMPERATURE CONSTANT AND KNOWN TO $\pm 0.05°C$ AFTER 20 MINUTES	DESIGN COMPLIES PRESUMING PERIODIC RECALIBRATION TO REMOVE DRIFT ERRORS
SEV TEMPERATURE UNIFORM TO $\pm 0.005°C$	DESIGN COMPLIES
EXPANSION SEV TEMPERATURE UNIFORM TO $\pm 0.005°C$ DURING ACTIVATION PERIODS OF UP TO 100 SECONDS	DESIGN COMPLIES

- CONCLUSIONS
  - ALL THERMAL CONTROL REQUIREMENTS SATISFIED
  - SPECIFIC THERMAL CONTROL REQUIREMENTS EXCEEDED WHEN
    - NECESSARY TO SATISFY ANOTHER REQUIREMENT
    - OR CAPABILITY CAN BE PROVIDED AT NO COST

TRW

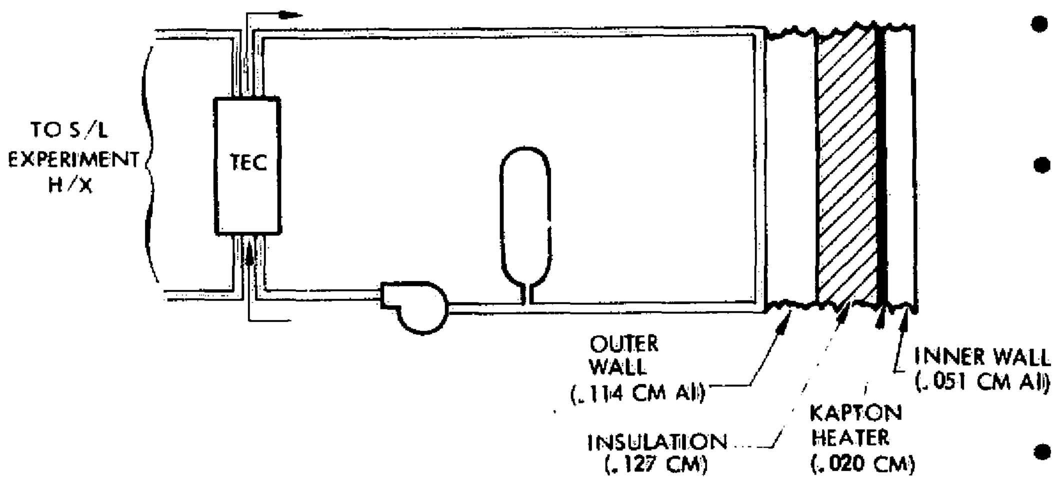
Inner wall cooling occurs by conduction through the insulation to the relatively colder outer wall. During a constant rate cooldown, the outer wall is maintained somewhat colder than necessary relative to the inner wall and the cooling rate of the inner wall is maintained by trimmer heaters bonded to it. Rapid changes in the cooling rate of the inner wall are accomplished by varying the power dissipated in the heaters. The outer wall temperature is controlled by a pumped fluid loop, cooled by a thermoelectric cooler. Because the trimmer heaters provide nearly instantaneous modification and control of the inner wall cooling rate, the outer wall temperature-time profile can be controlled with looser tolerances.

The temperature rise of the fluid in the outer wall cooling channels and the variable heat transfer coefficient produce a systematic large-scale temperature gradient in the direction of flow when the system is under load (i.e., during an expansion). The insulation layer between the high conductivity inner and outer walls attenuates small-scale temperature gradients, due to the finite spacing of the cooling channels. The larger scale gradient along the direction of flow is reduced by using a number of trimmer heaters in zones normal to the flow channels. Each heater zone has its own temperature sensor and its own controller. Satisfactory uniformity can be achieved using 5 ring-shaped zones on the cylindrical walls and 3 azimuthal zones on each end.

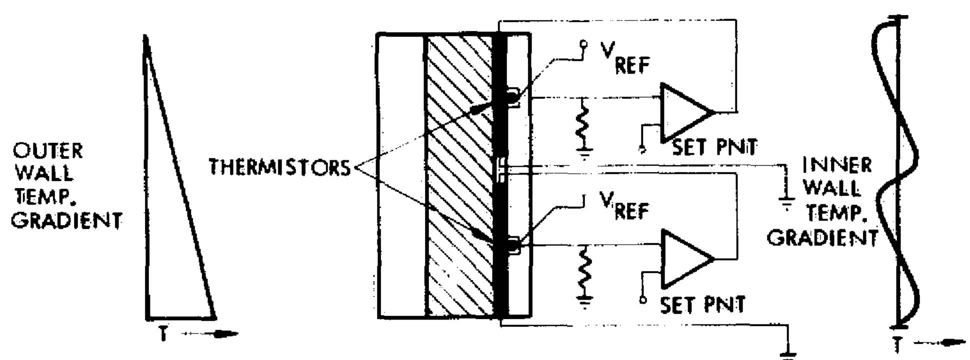
EXPANSION CHAMBER SUBSYSTEM

WALL THERMAL CONTROL CONCEPT

- MULTIPLE WALL CONCEPT



- INNER WALL TEMPERATURE CONTROL



- OUTER WALL CONTROLLED TO TEMPERATURE SLIGHTLY BELOW INNER WALL
- INNER WALL CONTROLLED BY BALANCE BETWEEN HEATER POWER AND CONDUCTION TO OUTER WALL
- SMALL SCALE TEMPERATURE GRADIENTS ATTENUATED BY INSULATION
  - GRADIENTS DUE TO SEPARATION BETWEEN COOLING CHANNELS
- LARGE SCALE TEMPERATURE GRADIENTS SYSTEMATIC
  - DUE TO COOLING FLUID TEMPERATURE RISE AND VARYING COEFFICIENT OF HEAT TRANSFER
- REDUCED BY USING ZONED, INDIVIDUALLY CONTROLLED HEATERS

Each window assembly consists of two transparent windows enclosing a layer of dry air or nitrogen, preventing condensation on the outer surface of the inner window during below ambient operation of the expansion chamber. The inner window is sapphire, for which the relatively high thermal conductivity permits reasonably accurate temperature control and uniformity. The outer window is fused silica, for which the relatively low thermal conductivity permits the outer surface to remain at or near ambient temperature without producing a large heat leak to the chamber.

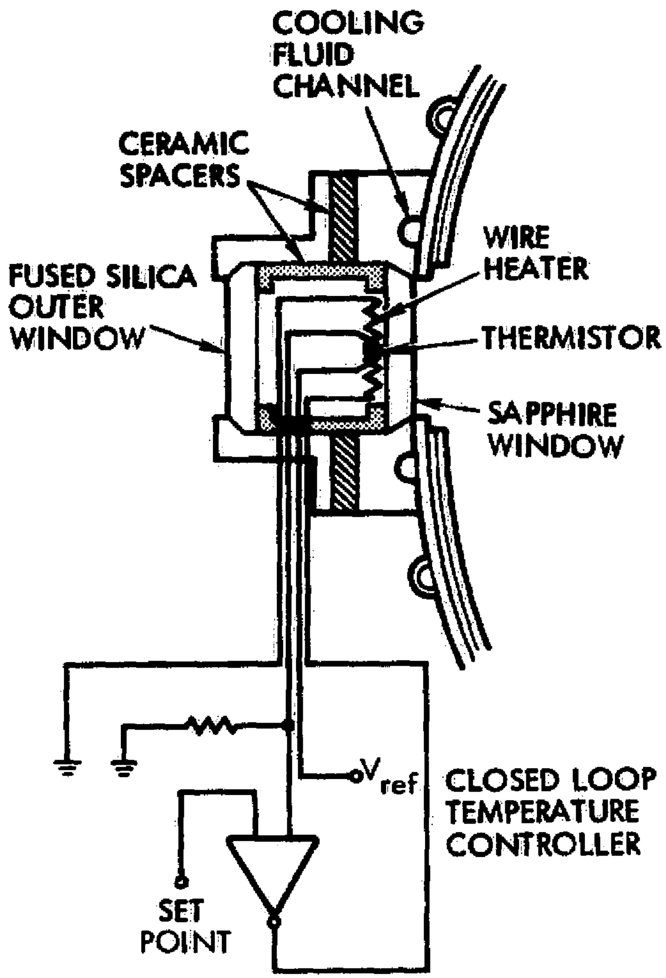
The sapphire window is enclosed in an aluminum housing which is cooled by dedicated cooling fluid passages. The cooling fluid passages prevent large thermal lags in the relatively massive housing, and limit the influence of the thermal lags on the surrounding outer wall. The sapphire window is cooled by conduction to the housing. A thermistor mounted on the window controls the power dissipated within a heater wire bonded to the window surface. The heater, bucking against the cooling due to the surrounding housing provides the thermal control for the window.

The outer window is mounted in a light aluminum housing which is thermally isolated from the inner window housing by a machineable ceramic thermal spacer.

The access port design is similar to the window design, except that the sapphire inner window is replaced by an aluminum plate, and the outer window is not present.

EXPANSION CHAMBER SUBSYSTEM

WINDOW/PORT THERMAL CONTROL CONCEPT



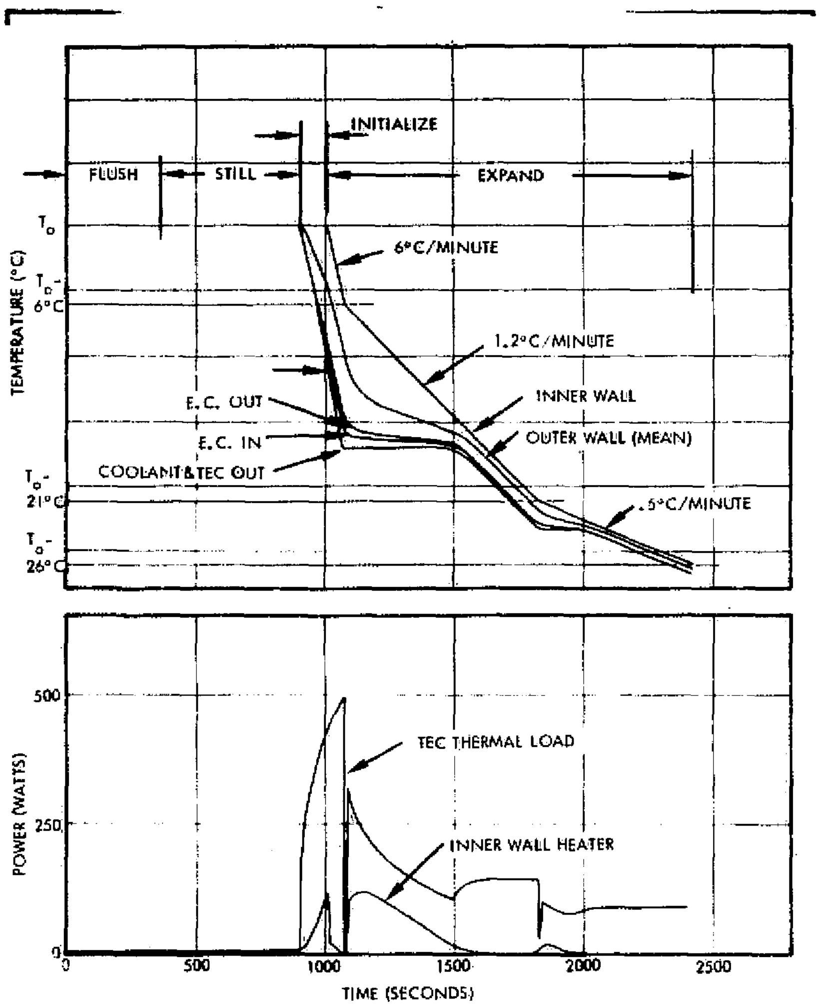
- DOUBLE WINDOW WITH DRY GAS SEALED WITHIN
- SAPPHIRE INNER WINDOW HAS GOOD THERMAL CONDUCTIVITY, UNIFORM TEMPERATURE
- CLOSED LOOP HEATER MAINTAINS INNER WINDOW SLIGHTLY ABOVE CHAMBER AIR TEMPERATURE ($\leq$0.5°C)
- COOLING FLUID CHANNELS WITHIN WINDOW HOUSING MINIMIZE THERMAL LAG OF RELATIVELY MASSIVE HOUSING, LOCALIZE DISTURBANCE OF OUTER WALL
- PORT CONCEPT SIMILAR
  - ALUMINUM BLANK REPLACES SAPPHIRE WINDOW
  - OUTER WINDOW NOT PRESENT

TRW

The low thermal mass of the expansion chamber outer wall, coupled with the small temperature difference between inner and outer walls during cooldown, allows us to establish the starting conditions for an expansion within a span of 100 seconds or less using moderate refrigeration loads. The short initialization time means that flushing and stilling can be carried out with no load on the system so that all temperatures are equal and conditions within the chamber are very isothermal. After stilling is complete and an isothermal initial condition is established, the initialization of the temperature difference between inner and outer walls is carried out so quickly that aerosol losses due to diffusion and coagulation can be neglected. The total time for initialization and the first 100 seconds of the expansion is 200 seconds or less, starting from a perfectly uniform initial state. SEV nonuniformities due to imperfect control and imperfect uniformity of walls and windows are minimized due to the brevity of the total process.

EXPANSION CHAMBER SUBSYSTEM

THERMAL CONTROL - OPERATING SEQUENCE



FEATURES

- INNER WALL TEMPERATURE RATE CHANGE VIRTUALLY INSTANTANEOUS
- RAPID INITIALIZATION SEQUENCE ALLOWS FLUSHING AND STILLING UNDER UNIFORM TEMPERATURE CONDITIONS
  - NO CONDENSATION DURING SAMPLE INJECTION
  - IMPROVED SEV UNIFORMITY AT START OF EXPANSION

CONCLUSIONS

- COOLING RATE REQUIREMENTS ARE MET WITH MODERATE REFRIGERATION LOADS
- $\ddot{T}$ (SLEW RATE) PERFORMANCE EXCEEDS SPECIFICATION

TRW

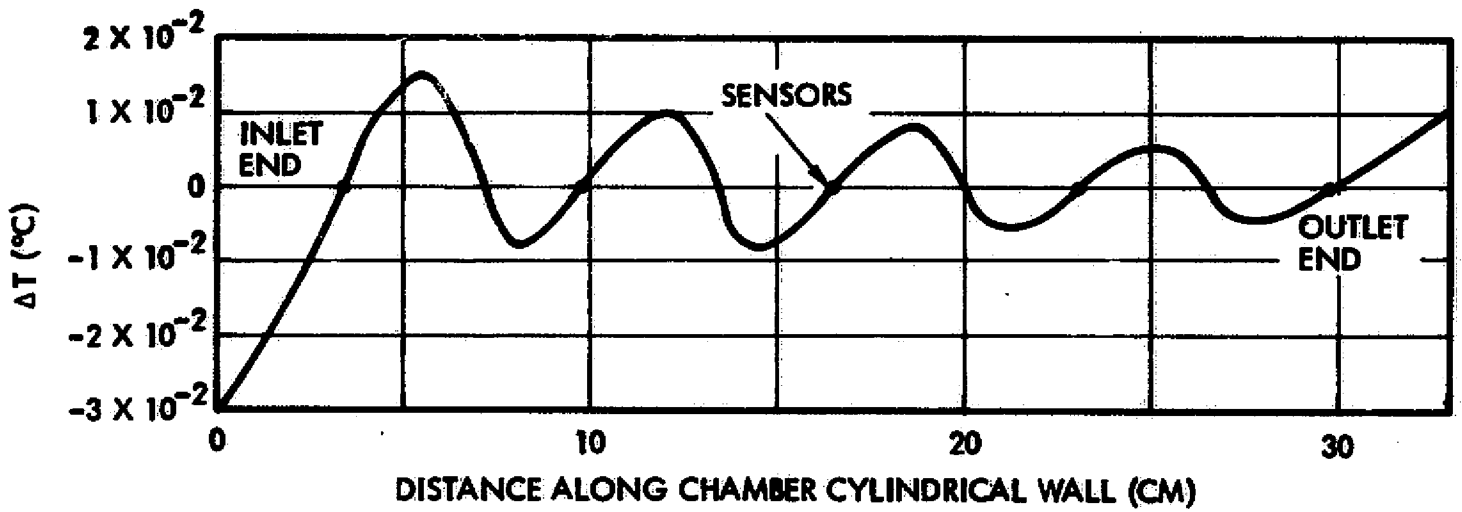
The plot on the facing page shows the temperature variation in the cylindrical inner wall of the expansion chamber in the direction parallel to the cooling channels due to the finite size of the zoned trimmer heaters. Conditions correspond to a cooling rate of $3^{0}C$/minute. The high thermal conductivity of the inner wall smooths out the profile at the interface between each pair of heaters and reduces the temperature variation. The profile shown assumes that each sensor is located at the geometrical center of the corresponding heater, and all heaters are the same size. Although the non-uniformities shown are clearly not large, they may be reduced still further by varying the zone heater width to reduce the temperature variation in the zone closest to the inlet, and also by locating the sensor away from the center of each zone to symmetrize the error.

Cooling flow residence times in the manifolds feeding the cylindrical wall cooling channels are minimized by introducing excess flow which is removed through symmetrical outlets, bypassing the cooling channels altogether. Residence times can be kept to about 1.1 seconds by this method. Sizing of the manifolds with respect to the cooling channels is such as to yield essentially equal flow rates in each of the channels.

EXPANSION CHAMBER SUBSYSTEM

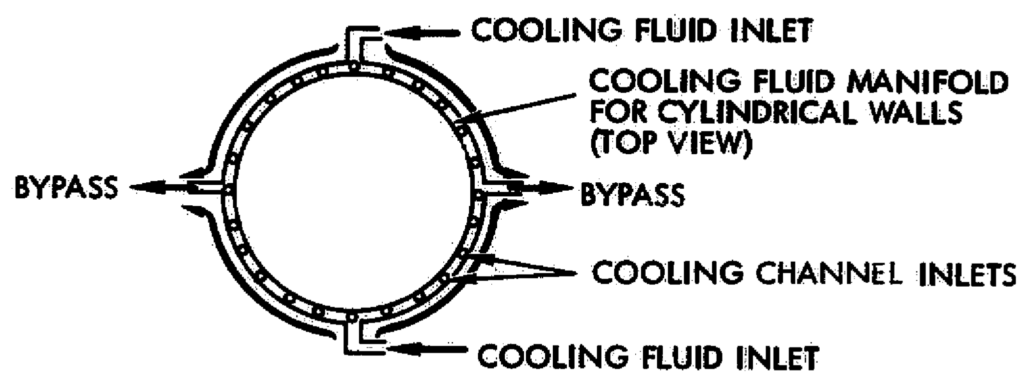
INNER WALL TEMPERATURE UNIFORMITY

- HEATER ZONE SAWTOOTH: $+1.5 \times 10^{-2}$°C, -3×10^{-2}°C



- COOLING FLUID MANIFOLD RESIDENCE TIME: $\pm 2.8 \times 10^{-2}$°C

- BYPASS FLOW LIMITS MANIFOLD RESIDENCE TIME TO ~ 1.1 SEC
- AT 3°C/MINUTE, 1.1 SEC = 0.055°C, OR ±0.028°C



TRW

Heater manufacturers assure us that heaters can be manufactured such that the power dissipation per unit area is uniform to much less than 1%. Hence, the nonuniformity in insulation resistance due to dimensional variation in insulation thickness is dominant over heater uniformity as an error source.

EXPANSION CHAMBER SUBSYSTEM

INNER WALL TEMPERATURE UNIFORMITY (CON'T)

- LARGE SCALE HEATER AND INSULATION NON-UNIFORMITY: $\pm 4.0 \times 10^{-2}$°C
  - HEATER NON-UNIFORMITIES EXPECTED TO BE NEGLIGIBLE
  - THERMAL RESISTANCE OF INSULATION DUE TO THICKNESS VARIATIONS TO VARY BY NO MORE THAN ±2%
  - REQUIRES INSULATION THICKNESS UNIFORMITY OF ~ ± 0.005 CM
  - TEMPERATURE DIFFERENCE BETWEEN INNER AND OUTER WALLS IS ~2°C AT 3°/MINUTE COOLING RATE
  - VARIATION IN INNER WALL TEMPERATURE DUE TO INSULATION NON-UNIFORMITY IS $\sim \pm(0.02)(2) = \pm 0.04$°C
- TOTAL NON-UNIFORMITY IN CHAMBER WALL: $\leq +8.3 \times 10^{-2}$, $\leq -9.8 \times 10^{-2}$
- CONCLUSIONS
  - WINDOWS/PORTS OCCUPY ~2% OF WALL AREA
  - REMAINING 98% OF WALL WILL SATISFY ±0.1°C UNIFORMITY REQUIREMENT AT $\dot{T} \geq -3$°C/MINUTE
  - UNIFORMITY REQUIREMENT SATISFIED

TRW SYSTEMS GROUP

Mean wall temperature control to $\pm 0.1^{\circ}C$ absolute accuracy at a $6^{\circ}C$/minute cooling rate and maximum $\ddot{T}$ can only be assured by periodically recalibrating the temperature sensors and electronic components to reduce drift errors.

EXPANSION CHAMBER SUBSYSTEM

MEAN WALL TEMPERATURE CONTROL ACCURACY

(WORST CASE CONDITION: $-6°C$/MINUTE, MAXIMUM $\ddot{T}$)

ERROR SOURCE	ERROR CONTRIBUTION	TOTAL ERROR
RANDOM ERRORS		
ELECTRONICS	$\pm 9.3 \times 10^{-3}$ °C	
SENSOR SELF HEATING	$\pm 2 \times 10^{-3}$ °C	
SENSOR MOUNT	$\pm 4.4 \times 10^{-2}$ °C	
SENSOR INITIAL CALIBRATION	$\pm 5 \times 10^{-3}$ °C	
		RSS RANDOM ERROR $= \pm 4.5 \times 10^{-2}$ °C
SYSTEMATIC ERROR (NO RECALIBRATION, 10 YEAR LIFETIME)		
COMPONENT DRIFT	$\pm 8.3 \times 10^{-2}$ °C	
UNCOMPENSATED OUTER WALL TEMPERATURE VARIATION	-3×10^{-2} °C	
		MAXIMUM SYSTEMATIC ERROR $= -1.13 \times 10^{-1}$ °C
		MAXIMUM TRACKING ERROR WITHOUT RECALIBRATION $= -1.58 \times 10^{-1}$ °C
SYSTEMATIC ERRORS (YEARLY RECALIBRATION)		
COMPONENT DRIFT	$\pm 8.3 \times 10^{-3}$ °C	
UNCOMPENSATED OUTER WALL TEMPERATURE VARIATION	-3×10^{-2} °C	
		MAXIMUM SYSTEMATIC ERROR $= -3.8 \times 10^{-2}$ °C
		MAXIMUM TRACKING ERROR WITH YEARLY CALIBRATION $= -8.3 \times 10^{-2}$ °C

- CONCLUSIONS

  REQUIRED TRACKING ERROR MET IF DRIFT OF ELECTRONIC COMPONENTS AND SENSORS IS PERIODICALLY REMOVED BY RECALIBRATION.

TRW

Under steady state conditions some of the inner wall temperature control errors are eliminated. Furthermore, with practically no thermal load on the system except for heat leaks, all surfaces exposed to the air are at essentially the same temperature. Hence, the SEV temperature can be controlled to better than $\pm 0.1^{\circ}C$.

EXPANSION CHAMBER SUBSYSTEM

SEV STEADY STATE TEMPERATURE CONTROL

- DETERMINED BY ABSOLUTE CONTROL OF CHAMBER WALLS
- 100% OF WALL CONTROLLABLE TO BETTER THAN ± 0.1 °C.
- SEV TEMPERATURE CAN BE SET TO BETTER THAN ±0.1°C
- SEV STEADY STATE TEMPERATURE CONTROL REQUIREMENT SATISFIED

TRW

The yearly drift in thermistor calibration is estimated to be 0.005^{o}C. Over a 10-year laboratory lifetime thermistor drift alone may equal the entire measurement accuracy requirement, leaving no allowance for other measurement errors. In order to achieve the specified accuracy it will be necessary to periodically recalibrate or replace the mounted thermistors, as well as the measurement electronics.

EXPANSION CHAMBER SUBSYSTEM

SEV STEADY STATE TEMPERATURE MEASUREMENT

- THERMISTORS MAY DRIFT AT UP TO .005 °C/YEAR
- OVER THE 10 YEAR LIFETIME OF THE LABORATORY, SENSOR DRIFT ALONE MAY EQUAL THE ± .050 °C ACCURACY REQUIREMENT
- YEARLY RECALIBRATION OR REPLACEMENT OF SENSORS IN EXPANSION CHAMBER AS WELL AS RECALIBRATION OF ELECTRONIC COMPONENTS TO REDUCE DRIFT RESULTS IN THE FOLLOWING ERROR BUDGET

RANDOM ERRORS			
ELECTRONICS	± .005		
SENSOR SELF HEATING	± .002		
SENSOR CALIBRATION	± .005		
SENSOR MOUNTING	± .040		
		TOTAL RANDOM ERROR	± .041 °C
SYSTEMATIC ERRORS			
THERMISTOR DRIFT	± .005		
		TOTAL SYSTEMATIC ERROR	± .005 °C
		TOTAL ERROR	± .046 °C

- SEV STEADY STATE MEASUREMENT ACCURACY REQUIREMENT IS SATISFIED.

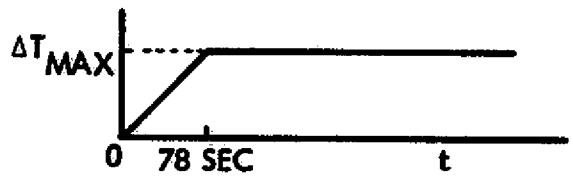
TRW SYSTEMS GROUP

SEV uniformity for the first 100 seconds of the expansion following a 78 second initialization period was calculated with a 1000 node SINDA computer program model of the gas within the chamber and the boundary conditions. Due to the linearity of the transient heat conduction equation the effects of various boundary condition variations on the SEV uniformity could be investigated individually and then superimposed to find the total effect of all the boundary condition variations.

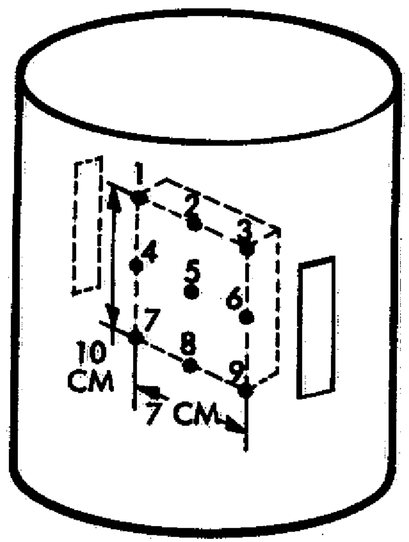
EXPANSION CHAMBER SUBSYSTEM

SEV UNIFORMITY

- SEV UNIFORMITY MODELLING
  - GENERATED 1000 NODE TRANSIENT THERMAL MODEL OF EXPANSION CHAMBER GAS, BOUNDARY CONDITIONS
  - ESTIMATED MAXIMUM SPATIAL VARIATION IN BOUNDARY CONDITIONS DUE TO EACH SOURCE OF NONUNIFORMITY
  - TEMPORAL VARIATION IN EACH BOUNDARY CONDITION MODELLED AS:



  - CALCULATED TEMPORAL VARIATION AT SEV NODES DUE TO EACH SOURCE OF NONUNIFORMITY. SEV NODES DEFINED AS SHOWN:



  - DUE TO LINEARITY OF TRANSIENT HEAT CONDUCTION EQUATION, SUPERIMPOSED RESULTS FOR EACH SOURCE TO GET NET EFFECT AT EACH SEV NODE

TRW

Under steady state operating conditions there is practically no load on the system except for heat leaks which are minimized with 5 cm of insulation. Consequently, all surfaces exposed to the air within the chamber are at essentially the same temperature. The SEV uniformity under these conditions should substantially exceed the requirement.

EXPANSION CHAMBER SUBSYSTEM

SEV UNIFORMITY(CON'T)

- STEADY STATE OPERATION
  - INNER WALL HEATERS, WINDOW HEATERS OFF
  - NO LOAD ON OUTER WALL COOLING FLUID LOOP
  - NO VARIATION IN BOUNDARY CONDITIONS
  - SEV UNIFORMITY $\ll \pm 0.005\,°C$

TRW

The boundary condition variations described on the facing page correspond to operation at a $6^{0}C/min$ cooling rate.

EXPANSION CHAMBER SUBSYSTEM

SEV UNIFORMITY (CON'T)

- VARIATIONS IN BOUNDARY CONDITIONS
  - AFTER INITIALIZATION OF INNER/OUTER WALL TEMPERATURE DIFFERENCE (78 SECONDS) AND 100 SECONDS OF EXPANSION AT 6°C/MINUTE
  - RANDOM VARIATIONS

    INNER WALL HEATER CONTROLLER ABSOLUTE ERROR (±0.10°C)

    INNER WALL HEATER CONTROLLER RELATIVE ERROR (±0.016°C)
  - SYSTEMATIC VARIATIONS

    INSULATION RESISTANCE VARIATION (±0.08°C)

    INNER WALL HEATER DENSITY VARIATION (NEGLIGIBLE)

    WINDOW TEMPERATURE OVERHEAT (0.5°C)

    WINDOW GRADIENT (±0.5°C)

    COOLING FLUID MANIFOLD RESIDENCE TIME (±0.055°C)

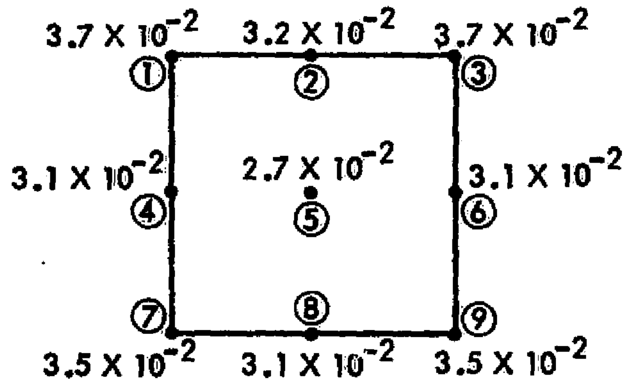
TRW SYSTEMS GROUP

The SEV uniformity requirement is satisfied, but there is no margin. In particular, the requirement would not be met if the initialization period were significantly extended, so that the time span between the uniform initial (steady state) condition and the end of the 100 second expansion were lengthened. One of the key features of TRW's Expansion Chamber design is the small initialization period provided by the large cooling capability and small inner-to-outer wall operating temperature difference.

EXPANSION CHAMBER SUBSYSTEM

SEV UNIFORMITY (CON'T)

- VARIATION IN SEV TEMPERATURES
  - RELATIVE TO NOMINAL SEV TEMPERATURE
  - AFTER INITIALIZATION OF INNER/OUTER WALL TEMPERATURE DIFFERENCE (78 SECONDS) AND 100 SECONDS OF EXPANSION AT 6°C/MINUTE



  - MAXIMUM NONUNIFORMITY (SEV NODES 1 AND 5) 0.010°C (±0.005°C)

- CONCLUSIONS
  - ALL SEV UNIFORMITY REQUIREMENTS SATISFIED

Expansion requirements impose structural requirements on the Expansion Chamber. The design is consistent with the pressures involved.

EXPANSION CHAMBER SUBSYSTEM

AEROSOL AND GAS PROCESS PERFORMANCE SUMMARY

- FLUSHING

REQUIREMENTS	PERFORMANCE
FLUSH 10 VOLUMES WITHIN 1000 SECONDS	DESIGN COMPLIES: FLUSH 10 VOLUMES IN $\approx$ 350 SECONDS

- STILLING

REQUIREMENTS	PERFORMANCE
RESIDUAL VELOCITIES $\leq$ 0.03 CM/SEC. PRIOR TO EXPERIMENT INITIATION	DESIGN COMPLIES. EVEN LOWER VELOCITIES POSSIBLE DEPENDING ON STILLING TIME.

- EXPANSION

REQUIREMENTS	PERFORMANCE
INITIAL PRESSURE: 0.8 TO 1.2 TIMES SPACELAB AMBIENT	INITIAL PRESSURE NOMINALLY 1040 MB. SATISFIES REQUIREMENT
EXPANSION RANGE: 500 MB BELOW INITIAL PRESSURE	DESIGN CONSISTENT WITH THIS REQUIREMENT
EXPANSION RATE: 0.1 TO 1.0 MB/SEC.	EXPANSION MECHANISM (PART OF FLUID SUB-SYSTEM) PERMITS EXPANSION AT RATES ABOVE 3 MB/SEC.

TRW SYSTEMS GROUP

The water vapor mixing ratio in the gas delivered to the Expansion Chamber must be known to $\pm 0.5\%$ for dew points above $5^{\circ}C$. It was assumed that the intent of the specification is to maintain this $\pm 0.5\%$ accuracy during the flushing, stilling, initialization, and expansion processes. The chamber has been designed to minimize water vapor losses due to condensation on inner wall surfaces during the expansion and to avoid condensation on colder outer wall surfaces by sealing the inner wall. In addition, flushing and filling the chamber with zero ΔT between the inner and outer walls assures no condensation in the fill ports.

EXPANSION CHAMBER SUBSYSTEM

AEROSOL AND GAS PROCESS PERFORMANCE SUMMARY (CONT)

- WATER VAPOR CONCENTRATION

REQUIREMENTS	PERFORMANCE
GAS DELIVERED TO EXPANSION CHAMBER: DEW POINT RANGE +20 TO -20°C	DESIGN CONSISTENT WITH THIS REQUIREMENT
RELATIVE HUMIDITY RANGE: 50% TO 99% REFERENCED TO CHAMBER TEMPERATURE	DESIGN CONSISTENT WITH THIS REQUIREMENT
WATER VAPOR MIXING RATIO: ± 0.5% FOR DEW POINTS GREATER THAN 5°C	DESIGN CONSISTENT WITH THIS REQUIREMENT
DEW POINT ACCURACY: ±1°C FOR DEW POINTS LESS THAN 5°C	DESIGN CONSISTENT WITH THIS REQUIREMENT
CONDENSATION ON INTERIOR SURFACES: CONTINUOUS FILMS OF CONDENSATE SHALL NOT OCCUR	DESIGN COMPLIES
DROPLET CONDENSATION SHALL OCCUR ONLY AT SUPERSATURATIONS > 3%	DESIGN COMPLIES

- CONCLUSION
  - ALL LEVEL 1 SPECIFICATIONS ARE MET.

TRW
SYSTEMS GROUP

Flushing tests conducted by MSFC indicate that the number and distribution of holes for sample inlet and withdrawal has little impact on chamber flushing efficiency. However, since the same holes are used for gas withdrawal during expansions, considerations of expansion uniformity might require a large number of holes. Accordingly, we initiated an analytical and experimental investigation of the expansion process.

EXPANSION CHAMBER SUBSYSTEM

EXPANSION ANALYSIS AND TEST

- PURPOSES
  - DETERMINE DISTURBANCE TO GAS IN SEV DURING AN EXPANSION
  - ESTIMATE THE NUMBER AND DENSITY OF VENTS REQUIRED TO WITHDRAW GAS FROM THE CHAMBER TO MINIMIZE THE SEV DISTURBANCE

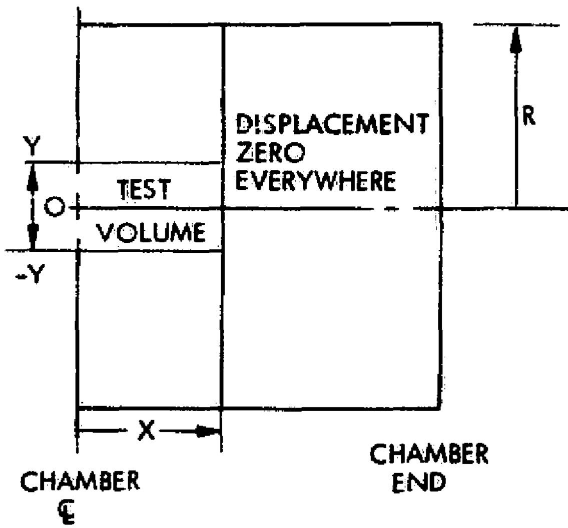
TRW

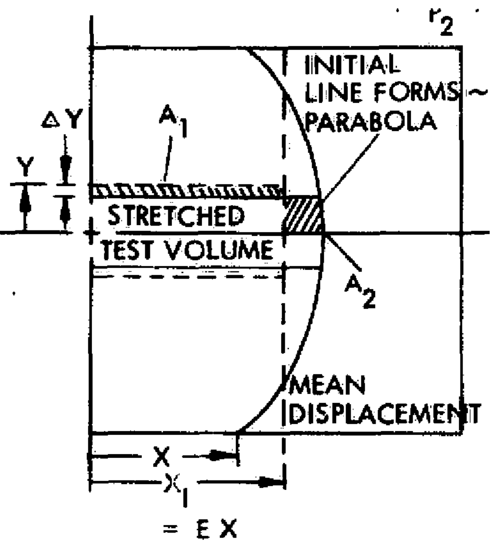
Starting from an initially uniform state, a line across the Expansion Chamber parallel to the end from which the gas is withdrawn is stretched into a parabola-like shape by a uniform expansion. The gas near the walls cannot move because of the presence of the boundary, and the displacement in the center is maximized. Test volumes near the center are stretched more than those near the outside boundary; if no gas flows from near the boundary towards the center, the pressure will be lower in the center of the chamber than at the outside. Because of the slowness of the expansion, pressure gradients cannot be maintained, and hence gas flows inward from outside the initial volume, as shown, to make up for the nonuniformity in displacement.

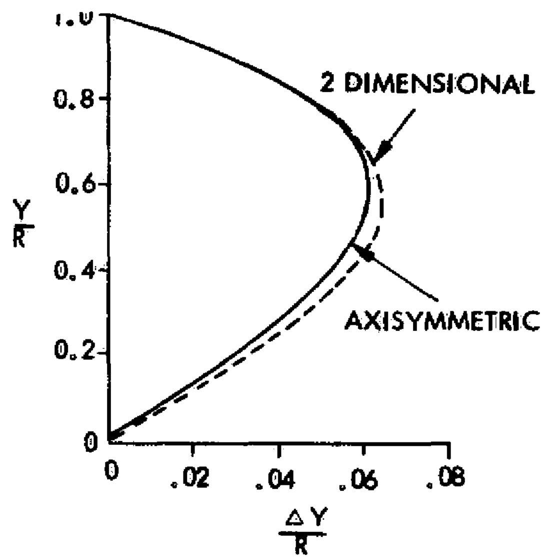
The plot at the extreme right showing the distance, Δy, from which the excess gas flows as a function of the initial distance, y, to the edge of the test volume, also shows that there is very little difference between the real axisymmetric case and a two dimensional case. In fact, the two dimensional case is somewhat more conservative since Δy is larger. Accordingly, we decided to perform a two dimensional simulation to verify the model and to determine the effect of hole distribution in degrading the expansion uniformity.

EXPANSION CHAMBER SUBSYSTEM

EXPANSION ANALYSIS AND TEST (CONT)







- NO PRESSURE GRADIENTS IN CHAMBER
- TEST VOLUME CONTRACTS BY ΔY TO MAKE UP FOR DIFFERENTIAL EXPANSION
- $A_1 = A_2$

- VERY LITTLE DIFFERENCE BETWEEN AXISYMMETRIC CASE AND TWO DIMENSIONAL CASE
- TWO DIMENSIONAL CASE CONSERVATIVE

TRW

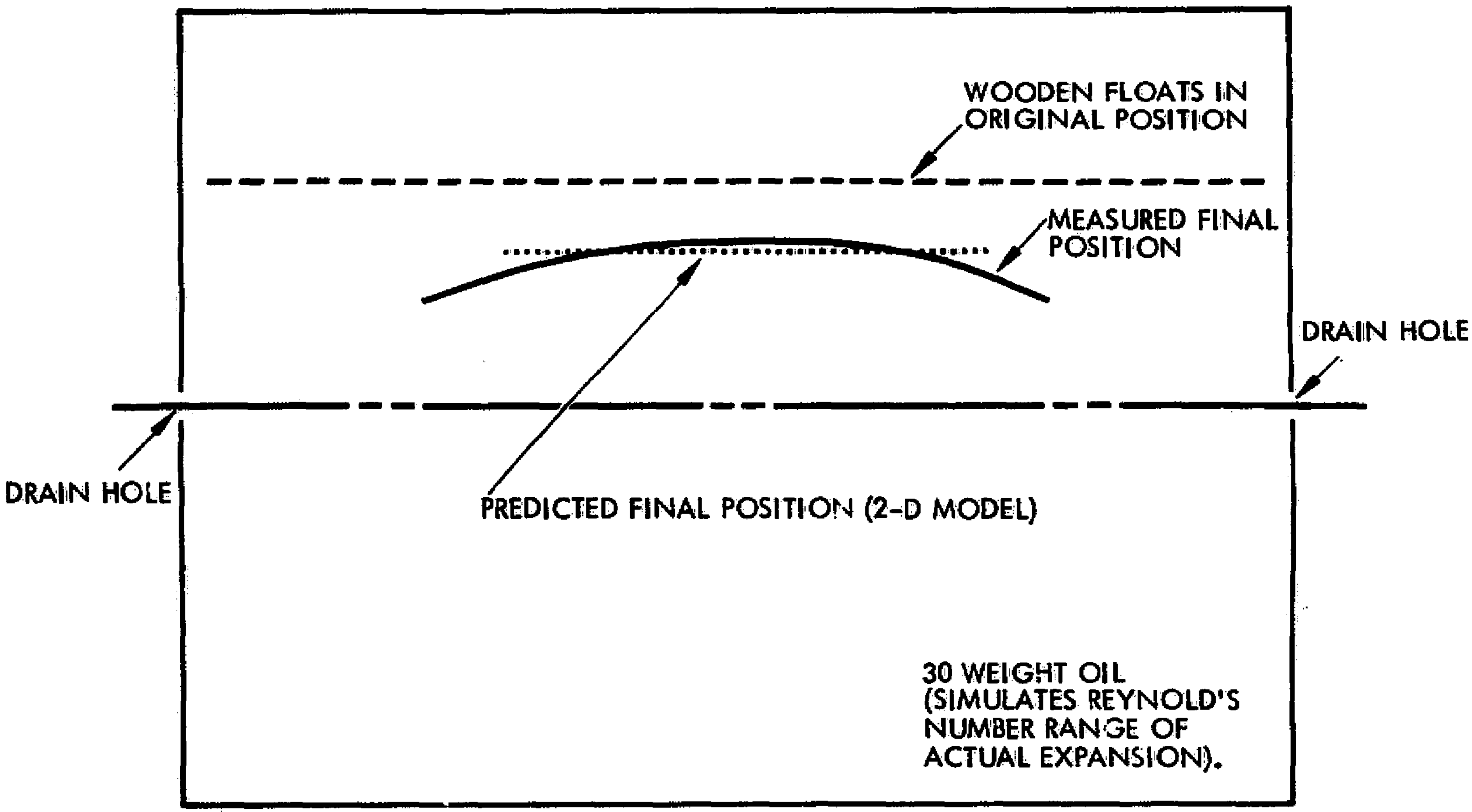
The experiment was conducted using 30 weight oil in a shallow pan. The viscosity of the oil produced a Reynolds number which simulated that for an actual expansion. Two holes, one in either end, were used to drain the oil, starting from a uniform initial state.

A row of wooden floats drifted to a steady state position which corresponded closely to that predicted by the model for large expansions. The shape of the line formed by the floats was somewhat deformed, apparently because only two holes were used to withdraw the fluid. Nevertheless. the disturbance introduced by the nonuniformity of fluid withdrawal was judged to be unimportant. We concluded that the number and distribution of holes used to withdraw the gas would have little effect on the uniformity of the expansion.

EXPANSION CHAMBER SUBSYSTEM

EXPANSION ANALYSIS AND TEST (CONTINUED)

- TEST (2 DIMENSIONAL TEST OF MODEL)



- PREDICTION VERIFIED
- NUMBER/DISTRIBUTION OF HOLES APPARENTLY HAS LITTLE EFFECT ON RESULT.

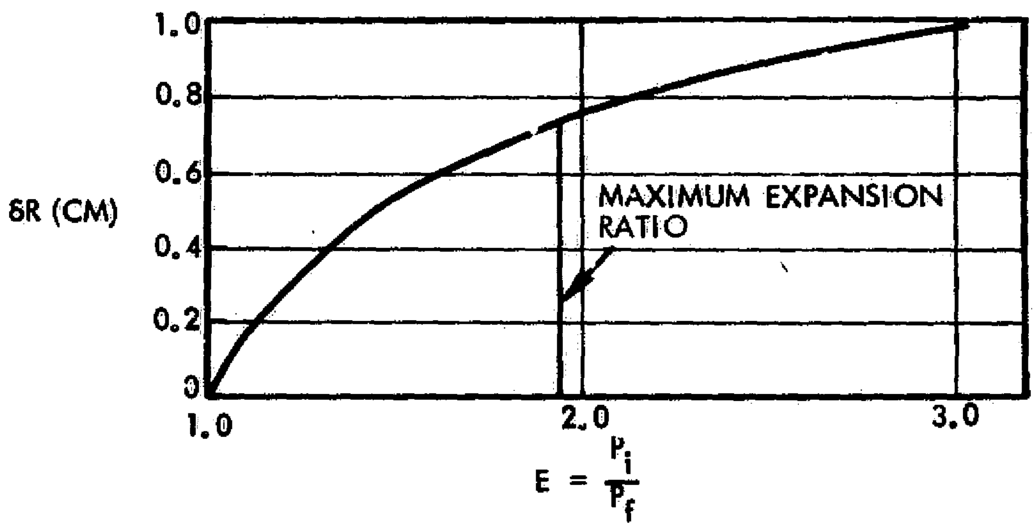
TRW

For the dimensions of the Expansion Chamber design and SEV presented here, the curve on the facing page shows the distance, δR, from which gas, initially outside the SEV, will be convected to points within the SEV during expansions of a given pressure ratio. For the maximum expansion permitted under the specification (500 mb) gas from a distance of .73 cm beyond the initial boundary of the SEV will enter the volume. This effect would be greater for any other orientation of the SEV.

EXPANSION CHAMBER SUBSYSTEM

EXPANSION ANALYSIS AND TEST (CONT'D)

- RADIAL MOTION OF GAS INTO SEV DURING EXPANSION (AXISYMMETRIC CASE)



- DURING DEEP EXPANSIONS, GAS FROM UP TO .73 CM OUTSIDE SEV BOUNDARY ENTERS SEV.
- DISTURBANCE IS MINIMIZED FOR SEV MAXIMUM DIMENSION ORIENTED ALONG CYLINDER AXIS

TRW

To prevent loss of water vapor due to condensation on the cold outer wall, the inner wall is sealed. The insulation between inner and outer walls must be vented since the inner wall is not thick enough to withstand a significant pressure difference. This is accomplished by venting through the outer wall. Expansion rates are so low that a single 1/8-inch diameter tube is large enough to vent the entire cylindrical wall. Pressure drops due to flow within the insulation are negligible.

EXPANSION CHAMBER SUBSYSTEM
WATER VAPOR LOSSES

- LOSS MECHANISMS
  - CONDENSATION ON INNER WALL DURING EXPANSION
  - CONDENSATION ON COLDER OUTER WALL IF INNER WALL NOT SEALED
- REMEDIES
  - INNER WALL COATED WITH HYDROPHOBIC COATING
  - OUTER WALL DOES NOT CONTACT GAS
    - INNER WALL SEALED
    - INSULATION MUST BE VENTED TO CHAMBER PRESSURE FOR STRUCTURAL REASONS
    - VENTING TAKES PLACE THROUGH OUTER WALL

TRW SYSTEMS GROUP

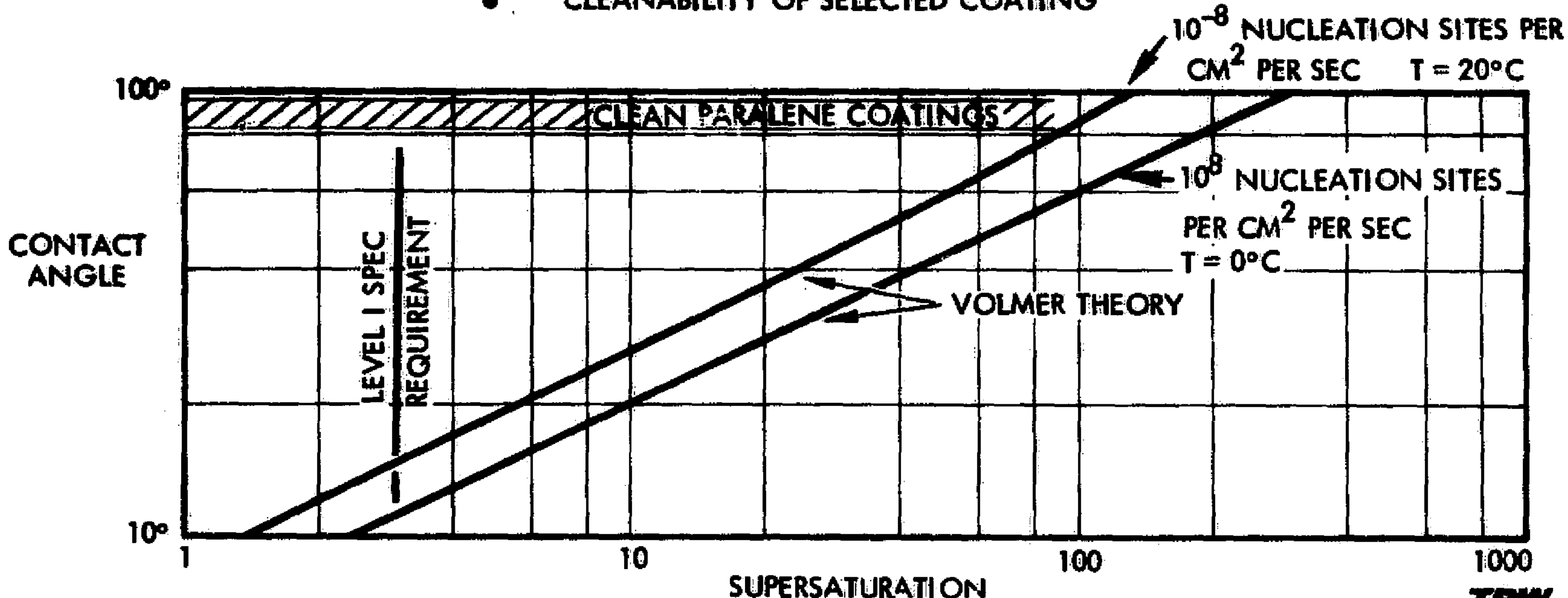
C-2

The Volmer theory predicts the critical supersaturation at which nucleation begins on a solid surface as a function of the contact angle for liquid droplets on the surface. Based on contact angle measurements, clean Paralene surfaces should be capable of withstanding supersaturations approaching 100% before condensation starts. In practice, however, this performance may be limited by contamination of the surface, and the extent to which the surface may be cleaned.

EXPANSION CHAMBER SUBSYSTEM

WATER VAPOR LOSSES (CONTINUED)

- HYDROPHOBIC COATINGS
  - BASELINE CHOICE: PARALENES N, C, OR D.
  - REASONS FOR SELECTION
    - PERFORMANCE AS A HYDROPHOBIC COATING:
    - OPTICAL TRANSPARENCY
    - THIN FILM, NEGLIGIBLE THERMAL MASS
    - TRW HAS A PARALENE COATING FACILITY
  - QUESTIONS TO BE ADDRESSED
    - EFFECT OF CONTAMINATION ON CRITICAL SUPERSATURATION
    - CLEANABILITY OF SELECTED COATING



The Expansion Chamber contains an entrance illumination window for introducing light into the chamber, and an exit illumination window which leads to a light trap. If the exit window were not present, the temperature of the thin inner wall opposite the entrance window might be increased by an unacceptable degree due to the energy in illuminating light beam. Furthermore, the exit window and light trap reduce film fogging due to light scattered from the expansion chamber walls.

The chamber also contains a 2 cm diameter window for visual observation and a 4 cm diameter window for photography.

EXPANSION CHAMBER SUBSYSTEM
OPTICALINTERFACE PERFORMANCE SUMMARY

REQUIREMENTS	PERFORMANCE
HAVE A WINDOW FOR VISUAL OBSERVATIONS	2 CM DIA. WINDOW PROVIDED
HAVE PORTS TO ACCOMMODATE THE OPTICAL AND IMAGING SUBSYSTEM	2 - 25 X 2 CM ILLUMINATION WINDOWS, 1 - 4 CM DIA. CAMERA WINDOW PROVIDED
OPTICAL AND IMAGING SUBSYSTEM AND EXPANSION CHAMBER WILL NOT ADMIT IR RADIATION THAT WILL ADVERSELY AFFECT THERMAL REQUIREMENTS OF EXPANSION CHAMBER	IN ADDITION TO FILTERS IN THE ILLUMINATION TRAIN, SECOND ILLUMINATION WINDOW TRANSMITS ALL EXCESS LIGHT THROUGH EXPANSION CHAMBER, AVOIDS THERMAL DISTURBANCE OF LOW MASS WALL OPPOSITE INLET WINDOW. OUTLET WINDOW ALSO REDUCES BACKGROUND FOGGING OF FILM DUE TO LIGHT SCATTERED FROM CHAMBER WALLS

- EXPANSION CHAMBER OPTICAL INTERFACE REQUIREMENTS SATISFIED

TRW
SYSTEMS GROUP

The mechanical design requirements, imposed both directly and indirectly by the Level 1 Specification, are shown on the facing page. All requirements are satisfied by TRW's preliminary Expansion Chamber design.

EXPANSION CHAMBER SUBSYSTEM
MECHANICAL DESIGN REQUIREMENTS

- LEVEL 1 SPEC. REQUIREMENTS

REQUIREMENT	PERFORMANCE
MINIMUM INTERNAL VOLUME 25 LITERS	INTERNAL VOLUME: 31.75 LITERS
HAVE A PORT, 2 CM DIA., TO PERMIT INSERTION OF OBJECTS	DESIGN COMPLIES
CHAMBER CAN BE OPENED AND CLOSED IN 8 HOURS ON GROUND	DESIGN COMPLIES

- OTHER REQUIREMENTS, IMPOSED INDIRECTLY, INVOLVE
  - STRUCTURAL PROPERTIES
  - FABRICATION OF COMPLEX WALL SECTION
  - COOLING FLUID MANIFOLDS AND PLUMBING
- ALL REQUIREMENTS SATISFIED BY PRELIMINARY MECHANICAL DESIGN.

TRW

The cylindrical shape of the chamber side walls is interrupted by the illumination windows which run almost the whole length of the chamber. Consequently, the illumination window housings have been designed to stiffen the walls surrounding the openings.

For the flat end walls, the thermal control and pressure containment functions have been separated. The pressure load is carried by the domed plenums, which are not temperature controlled. The flat, thermal control wall structure does not have to withstand a pressure differential, which permits use of a thin, low mass structure.

EXPANSION CHAMBER SUBSYSTEM
STRUCTURAL PROPERTIES

- CYLINDRICAL WALLS
  - MAXIMUM STRENGTH/THERMAL MASS RATIO
  - ILLUMINATOR WINDOWS STRENGTHENED TO CARRY LOAD ACROSS GAP
- END WALLS
  - PRESSURE DIFFERENTIAL TAKEN ACROSS DOMED PLENUMS
  - FLAT THERMAL WALLS SEE NO PRESSURE DIFFERENTIAL
- MOUNTING
  - MOUNTED SYMMETRICALLY BY END FLANGES
  - ONLY ELEMENTS RIGID ENOUGH TO CARRY LOAD AND DISTRIBUTE IT UNIFORMLY TO WALLS
  - THERMAL ISOLATORS MINIMIZE HEAT LEAK FROM SUPPORT STRUCTURE

TRW

Two insulating materials are used in fabricating the Expansion Chamber. For the flat end thermal walls, a fibermetal material, made of sintered stainless steel wires and having good structural stability, is bonded between the inner wall heaters and the outer wall. For the cylindrical walls, a stainless steel Velcro material is used which, because of its uniform compressibility, achieves the required circularity and spacing uniformity between the inner and outer walls. Both types of insulation have very low thermal mass per unit volume (5 to 8% that of stainless steel) and thermal conductivities which are only 2 to 3 times that for air.

EXPANSION CHAMBER SUBSYSTEM
FABRICATION OF WALL SECTION

- FLAT END WALLS
  - FIBER METAL INSULATION BONDED TO OUTER WALL
    - GOOD STRUCTURAL STABILITY
  - HEATER, INNER WALL BONDED TO INSULATION
- CYLINDRICAL WALLS
  - HEATER, STAINLESS STEEL VELCRO BONDED TO INNER WALL ON MANDRIL
  - PUSHED INTO OUTER WALL ON MANDRIL
  - UNIFORM COMPRESSIBILITY OF VELCRO FINGERS MAINTAINS DIMENSIONAL STABILITY OVER BULK OF MATERIAL
  - BONDING AROUND WINDOWS, PORTS FIXES INSULATION THICKNESS IN WEAKENED AREAS, ALSO SEALS AGAINST CHAMBER GAS
  - MANDRIL REMOVED

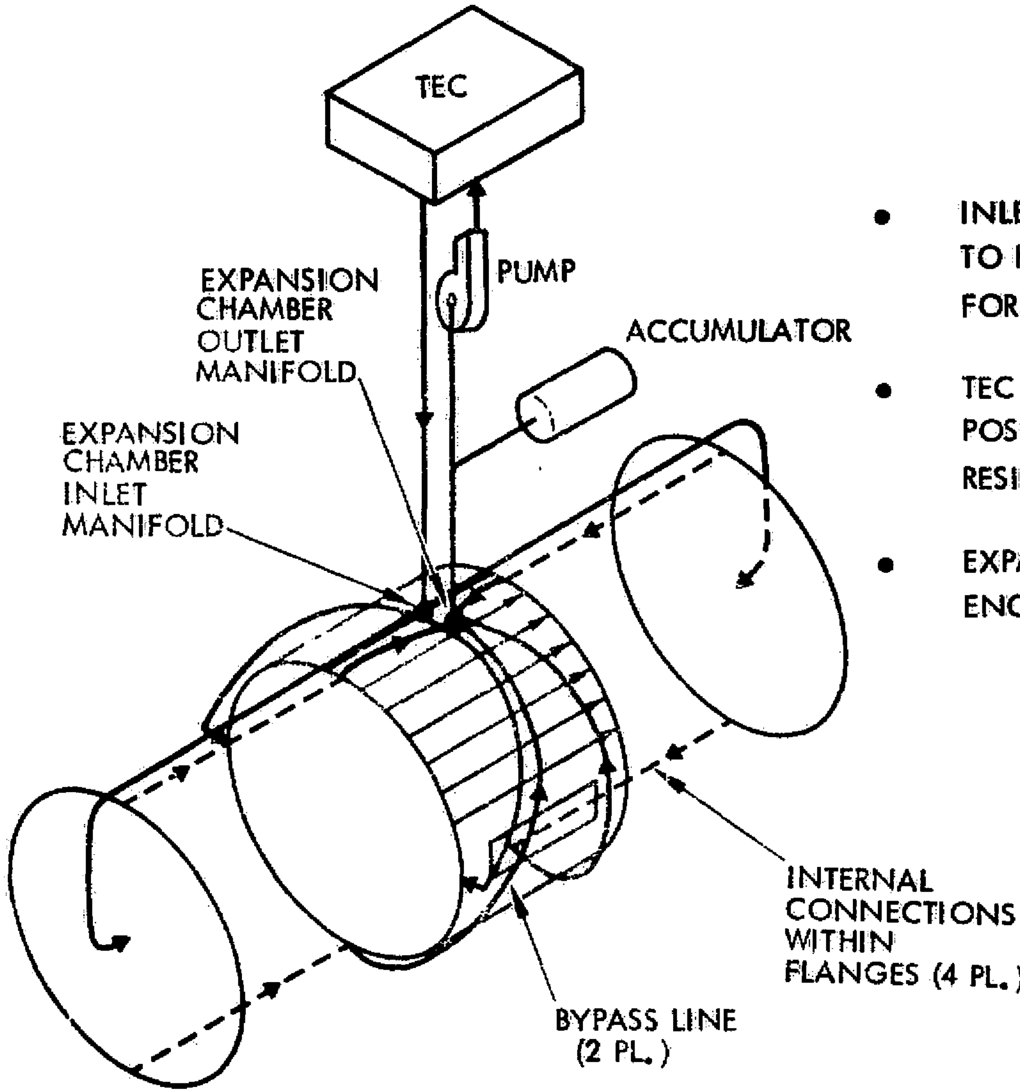
TRW SYSTEMS GROUP

The Thermal Control Subsystem for the Expansion Chamber is located as close as possible to the chamber to minimize line lengths and cooling fluid volume. Additionally, manifolds and cooling fluid passages within the Expansion Chamber itself are kept as short and narrow as possible to minimize thermal mass and residence times.

The inlet manifold, which couples the outlet from the TEC to the various expansion chamber cooling channels, is centrally located at the back of the chamber, directly opposite the camera window. The central location equalizes the residence times for fluid flowing to the two ends of the chamber, and to the two inlets to the cylindrical wall cooling channels.

EXPANSION CHAMBER SUBSYSTEM

COOLING FLUID MANIFOLDS AND PLUMBING



- INLET MANIFOLD CENTRALLY LOCATED TO KEEP LINE RESIDENCE TIMES EQUAL FOR ENDS
- TEC LOCATED AS CLOSE TO CHAMBER AS POSSIBLE TO MINIMIZE THERMAL MASS, RESIDENCE TIMES
- EXPANSION CHAMBER COOLANT PLUMBING ENCLOSED WITHIN INSULATION ENVELOPE.

TRW

STATIC DIFFUSION LIQUID (SDL) CHAMBER SUBSYSTEM

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TRW

The table on the facing page summarizes the performance of the SDL Subsystem design in relation to the Level 1 Specification requirements. All of the stated requirements are met or exceeded by the recommended design.

SDL SUBSYSTEM

REQUIREMENTS AND PERFORMANCE

REQUIREMENT	PERFORMANCE
• EXPOSE AEROSOL TO PRESELECTED S_M FROM 0 - 3%	DESIGN COMPLIES
• D/H LARGE ENOUGH TO AVOID ERRORS > 1% IN S_M WITHIN SEV	REQUIRED D/H $\geq$ 7.5 DESIGN D/H = 10
• SEV VOLUME $\geq 0.1\ CM^3$ WITHIN 0.97 S_M PROFILE	VOLUME $\leq 0.62\ CM^3$ WITHIN 0.97 S_M PROFILE, DEPENDING ON DESIRED VOLUME ERROR
• CAPABILITY TO PHOTOGRAPH SEV AND COUNT ALL DROPLETS WITH RADII $\geq 2\mu$	DESIGN COMPLIES
• SPATIAL MEAN TEMPERATURE OF SEV: 5 - 20 °C TEMPERATURE OF EACH PLATE KNOWN TO ± 0.1 °C ΔT WITHIN 4 H OF SEV BOUNDARY STABLE, UNIFORM AND KNOWN TO 0.010 °C	DESIGN COMPLIES
• WETTING SURFACES CAN BE CHANGED OR CLEANED	DESIGN COMPLIES
• PORTS AVAILABLE FOR OPTICAL AND IMAGING SUBSYSTEM PLUS VISUAL OBSERVATION	CYLINDRICAL GLASS DOUBLE WALL

• ALL LEVEL 1 SPECIFICATIONS ARE MET

TRW

The internal chamber configuration, sensitive experiment volume, wick system, thermal control and operational constraints were major considerations in the design of the Static Diffusion Liquid (SDL) Chamber. An additional design factor was our decision to use the SDL as an Aitken Particle Counter for obtaining total condensation nuclei (CN) counts and, in conjunction with the "black light" irradiation feature of the H_2SO_4 aerosol generator, to provide an air purity check at the exit of the Air Cleaning Subsystem. Each design element shall be discussed in detail; however, key features to look for include:

- Pumped fluid thermal control of the plates with computer designed counter-flow spiral flow channels for uniform heat transfer.
- A wick system with internal reservoirs sized for an entire mission.
- Cylindrical glass double side wall provides for illumination, photography, visual observation and, ultimately, light scattering measurements at multiple angles.

SDL SUBSYSTEM

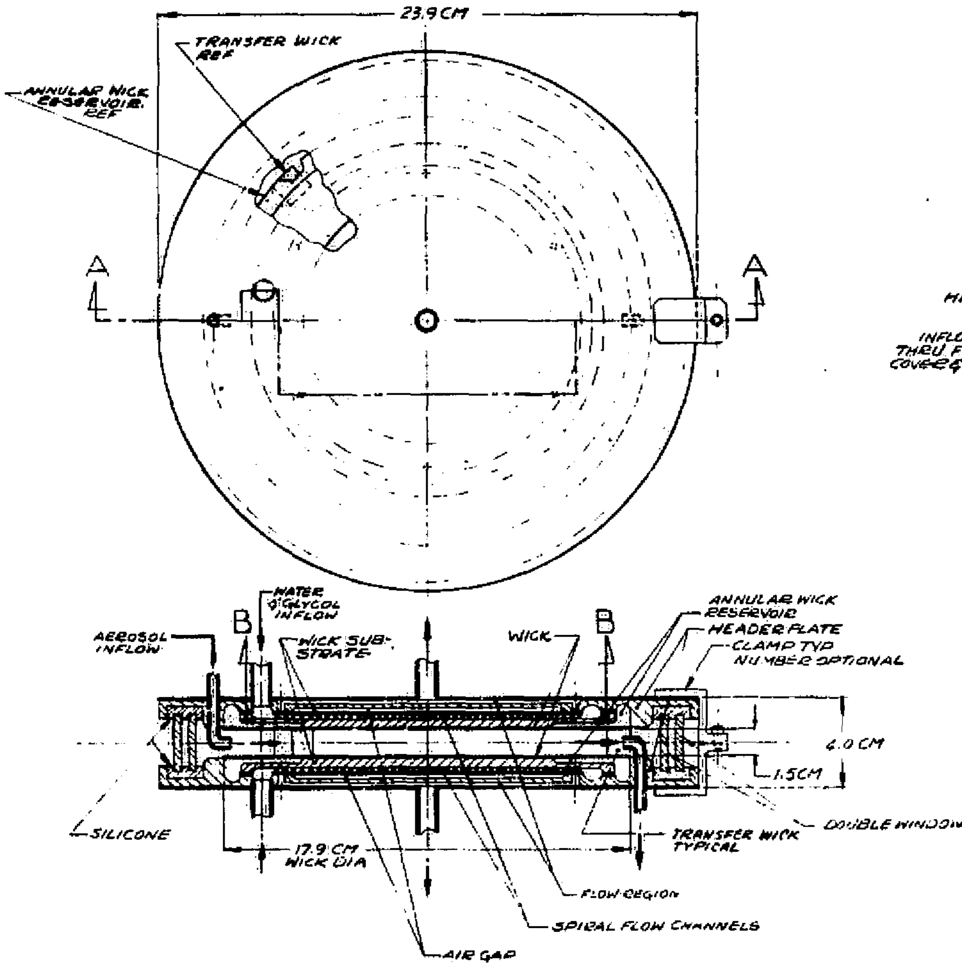
DESIGN ELEMENTS

- INTERNAL CHAMBER CONFIGURATION
- SENSITIVE EXPERIMENT VOLUME (SEV)
- WICK SYSTEM
- THERMAL CONTROL
- OPERATIONAL CONSTRAINTS
- USE AS AN AITKEN PARTICLE COUNTER

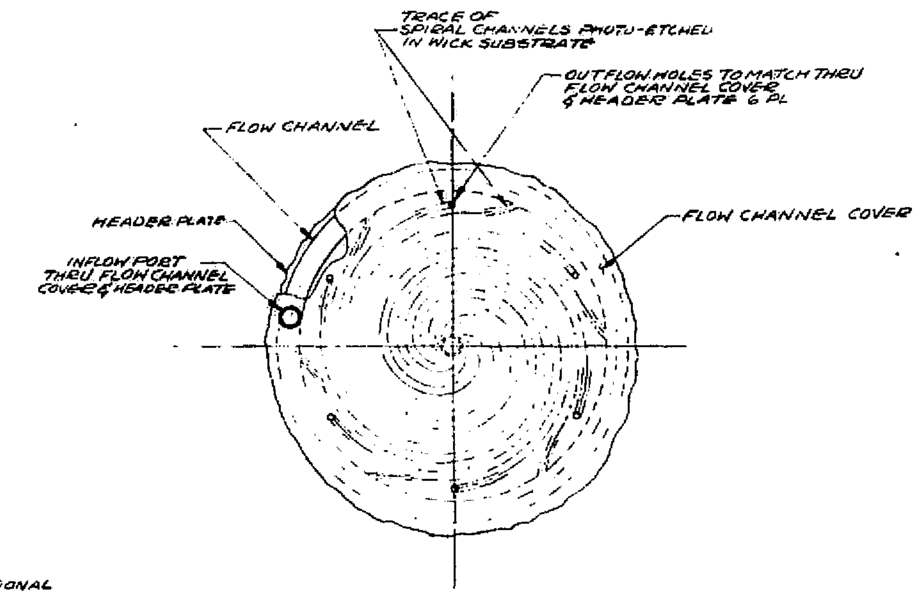
TRW

The SDL consists of two parallel plates with wetted wicks on their surfaces. The chamber is flushed with the aerosol sample, which then is allowed to still. A known supersaturation field develops due to the controlled temperature difference between the plates. Those aerosol particles with critical supersaturations S_c less than the supersaturation field activate and grow to observable size. Thus, as with the CFD, the SDL serves as a spectrometer in S_c. In addition, the SDL provides a potential capability for droplet growth studies and, as discussed later, will be used as an Aitken Particle Counter.

SDL SUBSYSTEM
PRELIMINARY DESIGN LAYOUT



SECTION A-A



SECTION B-B

The plate spacing (H) and the diameter of their wetted, temperature controlled zones were selected to meet the Level 1 Specifications that wall effects do not cause errors >1% in the supersaturation field within the SEV and that the SEV volume exceed 0.1 cm^3. Additional factors influencing their selection are shown on the facing page.

Depletion effects are considered minimal at S_m = 1% and N = 1000 particles/cm^3 if H = 1 cm according to P. Squires, "Diffusion Chambers for the Measurement of Cloud Nuclei," J. Recherches Atmosphériques, 1972.

The time required to establish the supersaturation profile is $\approx 2.9H^2$ (~7 diffusion time constants) according to W. P. Elliot, "Dimensions of Thermal Diffusion Chambers," J. Atmospheric Sciences, Vol. 28, 1971.

The selection of D = 15cm and H = 1.5cm assures a uniform temperature zone exceeding the required 4 plate spacings beyond the edge of the SEV.

SDL SUBSYSTEM

INTERNAL CHAMBER CONFIGURATION

PLATE SPACING (H) SHOULD BE SMALL TO:

- DECREASE DEPLETION EFFECTS BY GROWING DROPLETS
- DECREASE THE TIME (τ) NECESSARY TO ESTABLISH THE SUPERSATURATION PROFILE

PLATE SPACING (H) SHOULD BE LARGE TO:

- INCREASE THE RESIDENCE TIME IN THE SEV
- INCREASE THE SEV VOLUME (≥ 0.1 CM^3)

SUCCESSFUL TERRESTRIAL PRACTICE: H = 1.0 TO 1.5 CM

SELECTED SPACING: H = 1.5 CM

DIAMETER OF WETTED, TEMPERATURE CONTROLLED ZONE OF PLATES (D) MUST BE LARGE ENOUGH TO MINIMIZE WALL EFFECTS ON SEV

- ANALYSIS SHOWS $D/H \geq 7.5$ LIMITS ERROR IN S_M TO 1% WHEN $S_M = 0.1\%$. THUS, $D \geq 11.25$ CM

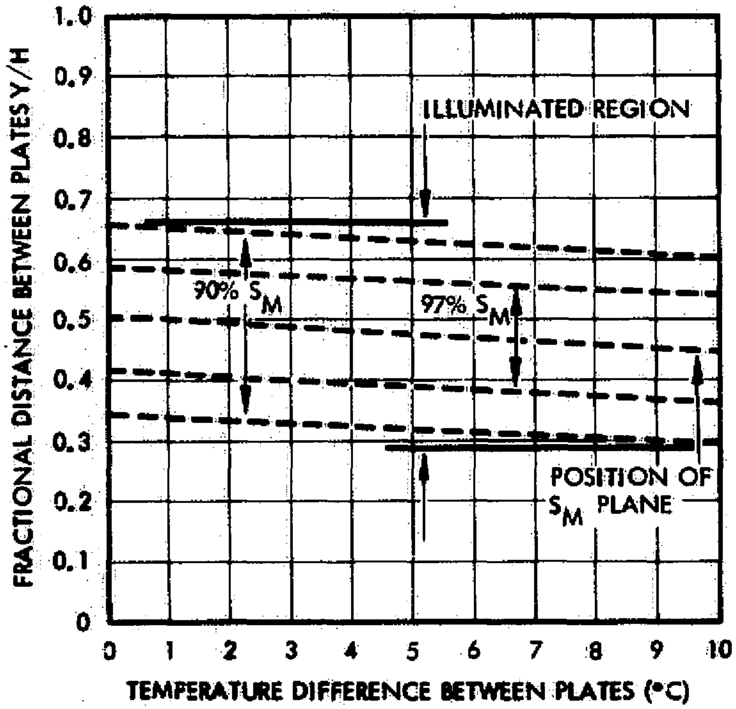
SELECTED DIAMETER OF WETTED, TEMPERATURE CONTROLLED ZONE: D = 15 CM

TRW

The Level 1 Specification requires that the SEV lie in a region of supersaturation above 97% S_m and that its volume is greater than 0.1 cm^3. A much larger region is illuminated and photographed, and the final definition of the SEV within 97% of S_m is made during data reduction by masking the film. Information at lower supersaturation levels is available and particularly useful when testing for air purity at low particle densities.

SDL SUBSYSTEM

SENSITIVE EXPERIMENT VOLUME (SEV)



- REQUIREMENTS:
  - SEV MUST LIE WITHIN $S > 0.97\ S_M$
  - SEV VOLUME $\geq 0.1\ CM^3$
- POSITION OF 0.97 S_M REGION SHIFTS TOWARD COLD PLATE AS ΔT INCREASES
- ILLUMINATED AND PHOTOGRAPHED REGION INCLUDES 0.90 S_M ZONE
  - SEV HEIGHT OF 0.26 CM AND WIDTH UP TO 2.4 CM DEFINED WITHIN 0.97 S_M PROFILE BY MASKING FILM DURING DATA REDUCTION
  - SEV DEPTH OF 1.0 CM DEFINED BY ILLUMINATION BEAM WITHIN CHAMBER
  - SEV VOLUME $\leq 0.62\ CM^3$
  - PHOTOGRAPHED VOLUME = $1.33\ CM^3$
  - ILLUMINATED VOLUME = $8.33\ CM^3$
- LARGE ILLUMINATED AND PHOTOGRAPHED VOLUMES INCREASE SENSITIVITY WHEN USED FOR AIR PURITY TEST

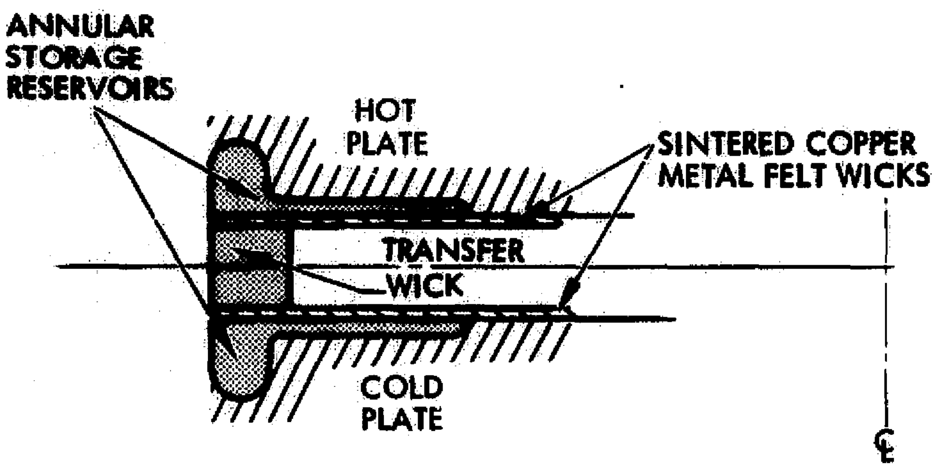
TRW

A thin copper metal felt wick sintered to the plates assures accuracy of the surface temperature measurement. These surface wicks communicate with annular water reservoirs so as to maintain the proper degree of saturation. Low conductivity fiber transfer wicks return water condensed on the cold plate to the hot plate. The reservoirs are sized to store sufficient water for an entire mission.

The SDL wick system is similar in concept to that used for the CFD.

SDL SUBSYSTEM

WICKING SYSTEM



- THIN (0.5 MM) METAL FELT COPPER WICKS SINTERED TO PLATES MINIMIZE TEMPERATURE DROPS (UNCERTAINTY IN $\Delta T < 0.001\ ^\circ C$)
- TRANSFER WICKS RETURN WATER FROM COLD TO HOT PLATE
- SINGLE CHARGE OF ANNULAR WATER STORAGE RESERVOIRS PROVIDES EXCESS CAPACITY FOR AN ENTIRE MISSION ASSUMING 900 VOLUME FLUSHES WITH 50% R. H. AIR

The Level 1 Specifications for thermal control of the SDL are met with a pumped coolant in flow through twelve spiral channels that are photo-etched into the plates using computer-drawn art work. The spirals alternate between inflow and outflow providing a counterflow situation which averages the coolant temperature change. After leaving the channels, the fluid flows radially inward in a guard flow gap to convect away heat leaks from ambient. An air gap isolates the plates from the guard flow (see SDL layout for details).

SDL SUBSYSTEM

THERMAL CONTROL OF PLATES

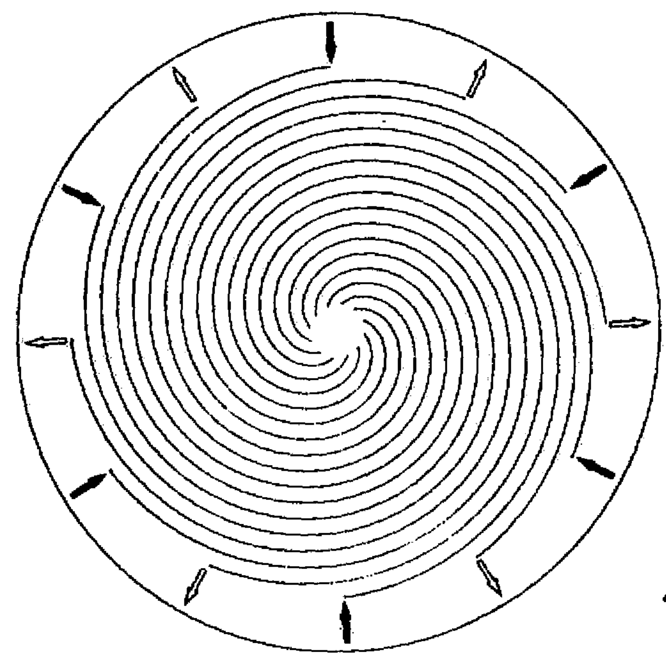
REQUIREMENTS AND OBJECTIVES:

• OPERATING TEMPERATURE RANGE	$5 \leq T_M \leq 20\ °C$
• TEMPERATURE MEASUREMENT ACCURACY	± 0.1 °C
• ΔT STABILITY, UNIFORMITY AND ACCURACY	± 0.01 °C
• RANGE IN ΔT	0 – 10 °C

DESIGN APPROACH:

- PUMPED WATER/ETHYLENE-GLYCOL SOLUTION IN SPIRAL CHANNELS PROVIDES UNIFORM THERMAL RESISTANCE. CONSTANT CHANNEL SURFACE AREA PER UNIT PLATE AREA.
- COUNTERFLOW IN ALTERNATE CHANNELS PROVIDES TEMPERATURE UNIFORMITY
- AIR GAP AND GUARD FLOW ISOLATES PLATES FROM AMBIENT HEAT LEAKS

COMPUTER-GENERATED CHANNEL PATTERN



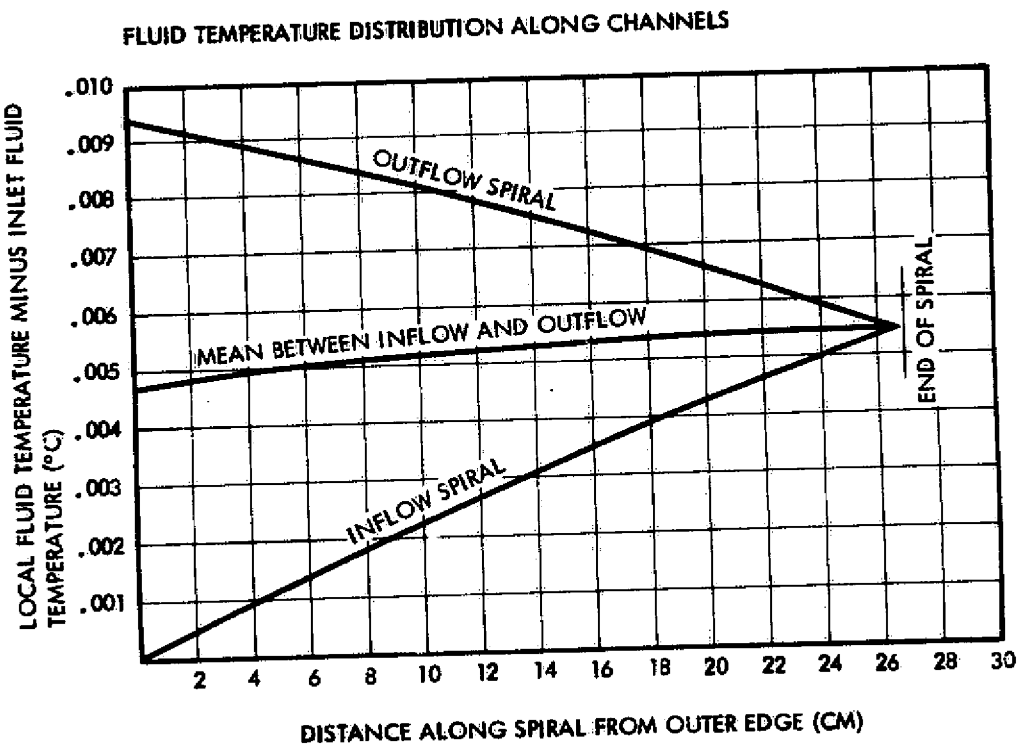
SPIRAL FLOW CHANNELS WITH ALTERNATE INFLOW AND OUTFLOW

TRW

The counterflow spiral cooling channels provide a uniform source and sink for heat to the SDL plates. Thermal analyses of the cold plate indicates that the high conductance of the 0.32 cm thick copper effectively averages the temperature rise between adjacent channels, yielding a very uniform temperature distribution. At worst-case conditions ($\Delta T = 10^{0}C$) the predicted plate uniformity within 6 cm (4 plate spacings) of the SEV is better than $\pm 0.001^{0}C$ compared with the $\pm 0.010^{0}C$ requirement.

SDL SUBSYSTEM

THERMAL CONTROL PERFORMANCE CALCULATIONS



- $\Delta T = 10\,°C$
- TOTAL HEAT LOAD = 1 WATT
- TOTAL FLOW RATE = 91 KG/HR
- MATERIAL: COPPER
- $\Delta P = 0.12$ PSI

- PLATE UNIFORMITY WITHIN FOUR PLATE SPACINGS OF SEV BETTER THAN ± 0.001 °C

TRW

Precautions must be taken in operating the SDL to avoid transient supersaturations in excess of the desired S_m; otherwise nuclei with $S_c>S_m$ will activate and grow. Drying the sample air to a dew point below T_c avoids problems arising from the incoming sample contacting a cold dry sidewall. Similarly, assuring that the sample temperature exceeds T_h avoids problems arising when air passes over a warm, wet surface. However, it is also important to avoid rapid increases in the hot plate temperature. This leads to transient supersaturations because the development of the concentration profile leads that of the temperature profile. Depending on the ultimate ΔT, a step increase in hot plate temperature can lead to transient supersaturations several times higher than the steady state value. Since this effect must disappear for an infinitely slow rate of increase in hot plate temperature, there exists a maximum dT/dt for which the transient supersaturation is acceptable (say 1% of S_m). This maximum dT/dt must be calculated with a transient diffusion analysis.

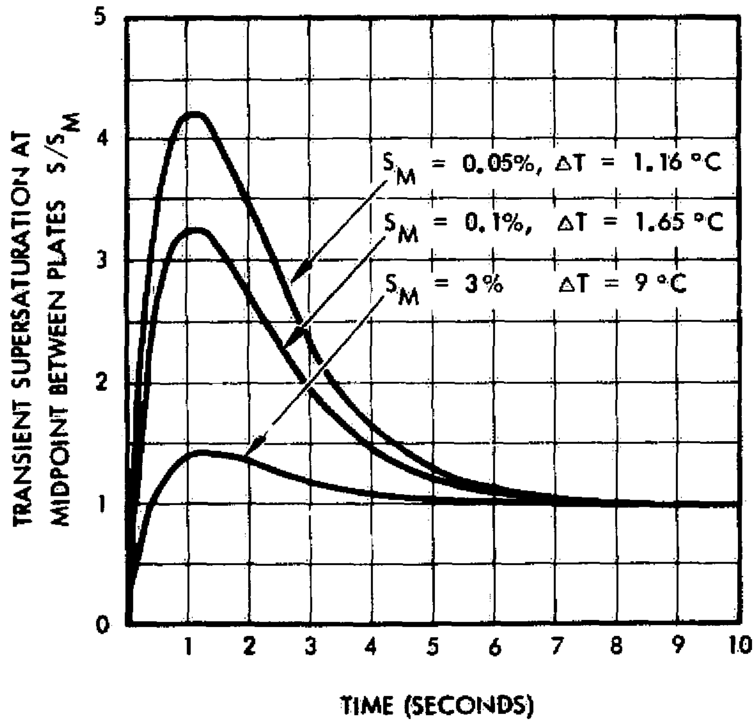
In view of these phenomena, when the SDL is operated by ramping to the desired ΔT after flushing and stilling at zero ΔT, the cold plate temperature will be lowered and the hot plate held constant. This permits a rapid approach to S_m without the possibility of transient supersaturations.

These same phenomena limit the usefulness of the thermal reversal concept for increasing residence time in the SEV. Reversing the plate temperatures too rapidly causes serious transient supersaturation errors. Reversing them too slowly allows droplets to migrate out of SEV. Detailed analysis may show there is no satisfactory reversal rate.

SDL SUBSYSTEM

OPERATIONAL CONSTRAINTS

TRANSIENT SUPERSATURATION DUE TO A STEP INCREASE IN HOT PLATE TEMPERATURE FROM ZERO ΔT (NORMALIZED BY STEADY-STATE VALUE OF S_M)



- TRANSIENT SUPERSATURATIONS IN EXCESS OF S_M CAUSE ACTIVATION OF NUCLEI WITH $S_C > S_M$, YIELDING ERRORS
- TO AVOID TRANSIENT SUPERSATURATIONS:
  1) SAMPLE AIR IS DRIED TO A DEW POINT $< T_C$
  2) AIR SAMPLE TEMPERATURE MUST BE $\geq$ HOT PLATE UPON ENTRY
  3) STEP INCREASES IN HOT PLATE TEMPERATURE ARE NOT PERMISSIBLE
- ΔT SHALL BE ESTABLISHED BY LOWERING COLD PLATE TEMPERATURE
- THERMAL REVERSAL CONCEPT FOR INCREASING RESIDENCE TIME IN SEV SUFFERS TRANSIENT SUPERSATURATIONS

TRW

The SDL will be used in an expansion mode to serve as an Aitken Particle Counter. Real time monitoring will be by visual observation through the glass walls at a $\sim 45^0$ forward scattering angle. Permanent data will consist of photographs.

When used for a total CN count, the sample will be drawn from the saturator outlet flow providing particle densities of 100 to 1000 particles/cm^3. When used for the air purity check, the sample is drawn from the outlet of the H_2SO_4 generator (where the sample is irradiated). The cleanliness level must be 0.1 particle/cm^3 at this point in order to meet the Level 1 Specification. Photographic data acquisition with the SDL is sufficiently sensitive to measure the 100 to 1000 droplet/cm^3 densities with reasonable accuracy (photographed volume = 1.33 cm^3). However, visual observation of the entire illuminated volume (8.33 cm^3) is required to detect droplet densities of order 0.1/cm^3.

SDL SUBSYSTEM

OPERATING THE SDL AS AN AITKEN PARTICLE COUNTER

- THE SDL WILL BE USED AS AN AITKEN PARTICLE COUNTER FOR TWO PURPOSES:
  1) FOR A TOTAL CN COUNT INCLUDING ALL PARTICLES WITH $r \geq 0.001$ μM
  2) FOR TESTING THE AIR PURITY EXITING THE AIR CLEANING SUB-SYSTEM AFTER IRRADIATION IN THE H_2SO_4 GENERATOR
- THE HIGH SUPERSATURATIONS NECESSARY TO OBTAIN AN AITKEN COUNT WILL BE PRODUCED BY EXPANDING THE CHAMBER VOLUME FROM AN ISOTHERMAL CONDITION NEAR AMBIENT TEMPERATURE
- TYPICAL OPERATING SEQUENCE
  1) FLUSH SDL WITH 10 VOLUMES (95 SECONDS AT 50 CM^3/SEC)
  2) ALLOW 7 DIFFUSION TIME CONSTANTS (6 SEC) FOR THERMAL AND HUMIDITY EQUILIBRATION
  3) EXPAND THE SDL INTO A VACUUM PLENUM
  4) SIMULTANEOUSLY OBSERVE AND PHOTOGRAPH RESULTING DROPLETS

DROPLET DENSITY: FOR USE AS CNC = 100 - 1000 DROPLET/CM^3
FOR AIR PURITY CHECK ~ 0.1 DROPLET/CM^3

VISUAL OBSERVATION NECESSARY FOR 0.1 DROPLET/CM^3 SENSITIVITY

TRW

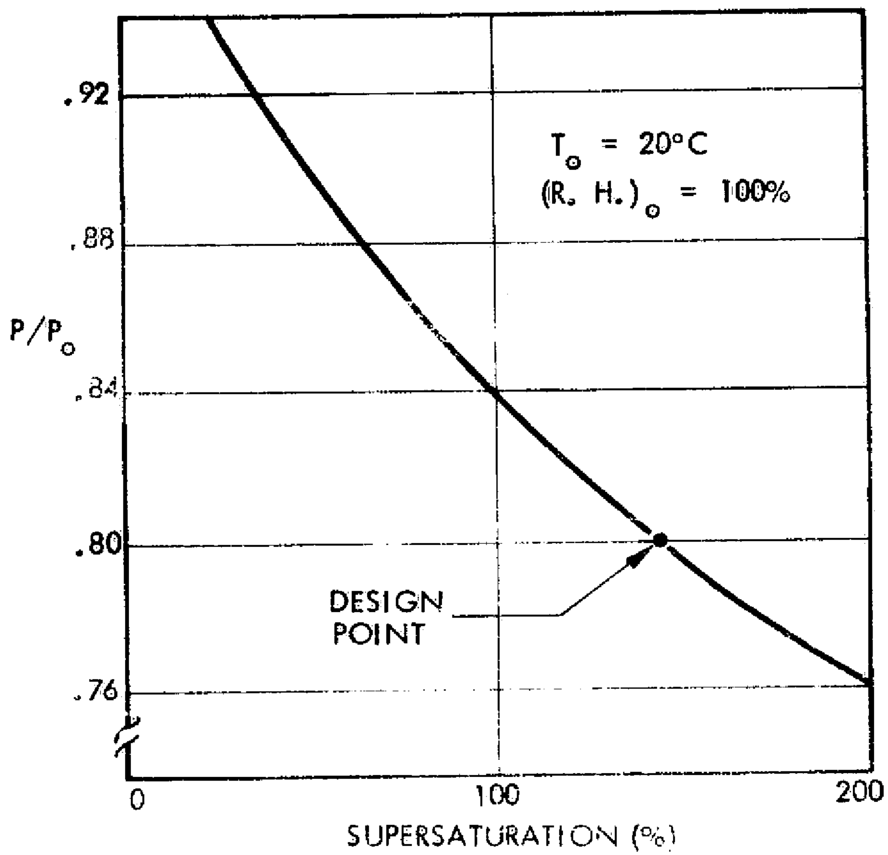
When used as an Aitken Particle Counter, the SDL must record all particles with radii $\geq 0.001\mu$. For NaCl particles, this corresponds to a critical supersaturation of 47%. It is necessary, however, to generate substantially higher supersaturations to provide for droplet growth before the supersaturation decays by condensation on the droplets and heating of the air. Typical condensation nuclei counters operate with maximum supersaturations of 100 to 300%.

Supersaturation is provided by expanding the chamber adiabatically, as shown by the curve on the facing page. However, to achieve supersaturations approaching those shown requires that the expansion be performed rapidly in comparison with the thermal time constant. Our design is for a 20% expansion in 0.1 seconds, yielding a maximum supersaturation of $\approx$130%.

SDL SUBSYSTEM

OPERATING THE SDL AS AN AITKEN COUNTER

EXPANSION RATIO VS. SUPERSATURATION



- TOTAL PARTICLE COUNT ABOVE $r = 0.001 \mu$
- FOR NaCl, $S_c = 47\%$
- REQUIRE S > 100% TO ASSURE DROPLET GROWTH BEFORE SUPERSATURATION DECAYS
- THERMAL TIME CONSTANT = 1.08 SEC
- DESIGN FOR 20% EXPANSION IN 0.1 SEC
- YIELDS MAXIMUM SUPERSATURATION OF:

$$S_{MAX} = 143\% \left[e^{-0.1/1.08}\right] = 130\%$$

TRW

CONTINUOUS FLOW DIFFUSION CHAMBER SUBSYSTEM

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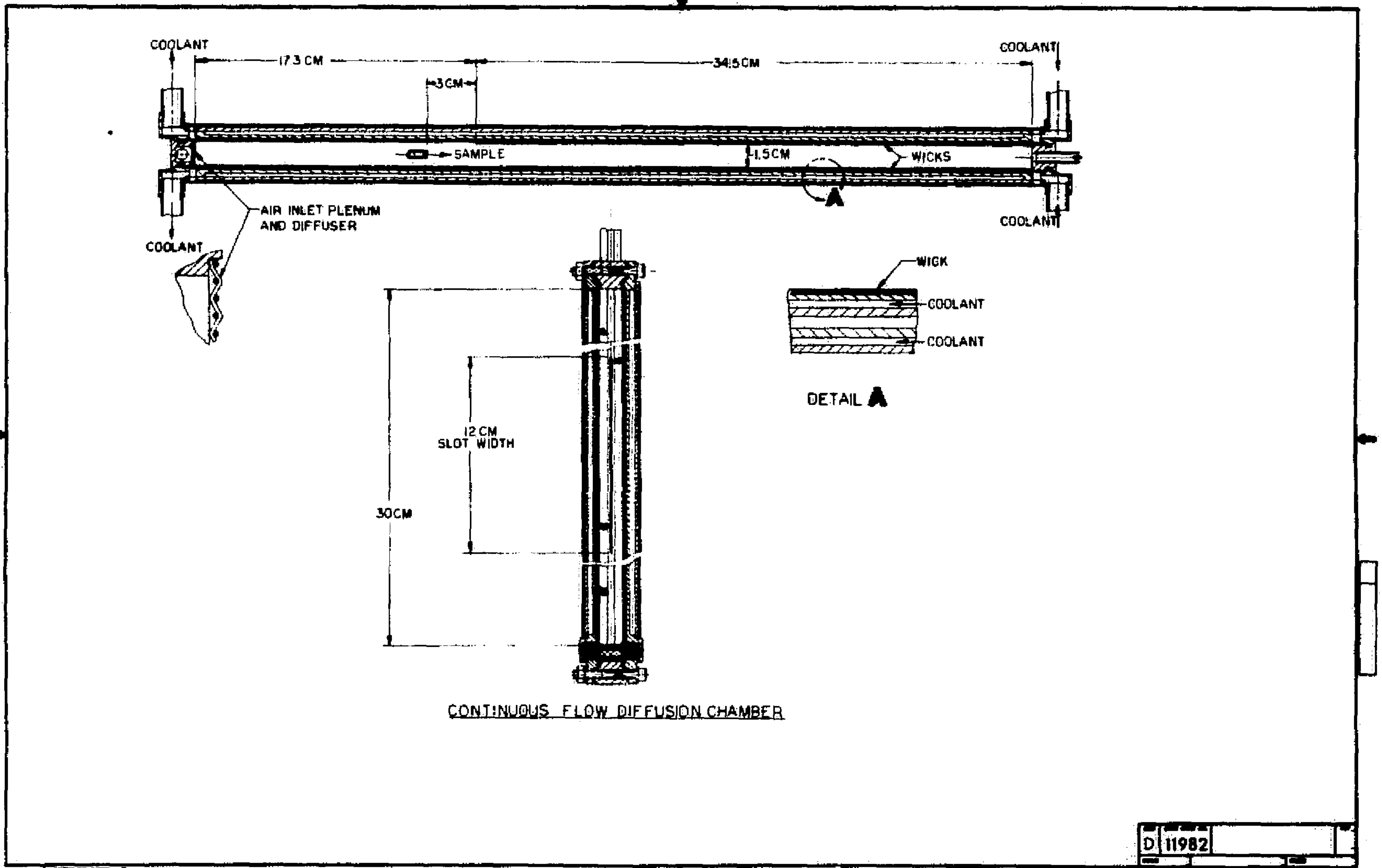
TRW

Physically, the CFD consists of two parallel plates with wetted wicks over appropriate lengths through which an aerosol sample is transported in a carrier air stream. The plates are maintained at a controlled temperature difference leading to a known supersaturation field between them. The aerosol passing through this field activates and grows to droplets of a size observable with an Optical Particle Counter. Only those aerosol particles with critical supersaturations (S_c) less than the supersaturation field undergo the activation and growth process. Thus, by varying the supersaturation field (ΔT between the plates), the CFD serves as a spectrometer in S_c.

A preliminary design layout of the CFD is shown on the facing page.

CFD SUBSYSTEM PRELIMINARY DESIGN LAYOUT



The CFD preliminary design was completed and presented at the Interim Review.

The table shown summarizes the internal configuration and sample entry parameters for the recommended design. Additional features of TRW's design are discussed in detail in the Interim Review documentation.

CFD SUBSYSTEM

SUMMARY OF RECOMMENDED CFD DESIGN PARAMETERS INTERNAL CONFIGURATION AND SAMPLE ENTRY

- DIMENSIONS

LENGTH OF ZONE 1	17.3 CM
LENGTH OF ZONE 2	34.5 CM
TOTAL LENGTH	51.8 CM
PLATE SPACING	1.5 CM
WIDTH OF CHAMBER	30 CM
POSITION OF SAMPLE SLIT	14.3 CM
LENGTH OF SAMPLE SLIT	12 CM
HEIGHT OF SAMPLE SLIT	0.0052 CM
THICKNESS OF SAMPLE SLIT	0.00127 CM
INTERNAL DIMENSIONS OF SAMPLE ENTRY CHANNEL	0.4 X 1.2 CM

- FLOW RATES

CARRIER FLOW RATE (≥20% PLATEAU)		15–83 CM^3/SEC
SAMPLE FLOW RATE (CONSTANT f_s DESIGN)		0.4 CM^3/SEC
MAXIMUM DROPLET FLOW ($S'_M/S_M = 0.99$)	0.1% S_M	192 DROPS/SEC
	0.5% S_M	470 DROPS/SEC
	≥1% S_M	885 DROPS/SEC

TRW

SCIENTIFIC SUBSYSTEMS

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TRW SYSTEMS GROUP

AEROSOL GENERATOR AND COUNTER SUBSYSTEMS

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TRW

The table on the facing page provides an overview of the Aerosol Generator Subsystem in terms of how the TRW design complies with the Level I Specification requirements.

AEROSOL GENERATOR SUBSYSTEM

REQUIREMENTS AND PERFORMANCE

LEVEL I SPEC. PARA. 3.1.6.3	REQUIREMENT	APPROACH	PERFORMANCE
A.1	Na Cl AND H_2SO_4 AEROSOLS	TRW DESIGNED:	
A.1.a	• PARTICLES < 0.1 μM WITH < 0.1 P/CM^3 HAVING RADII > 0.1 μM	• HOT WIRE Na Cl GENERATOR	PER SPEC.
A.1.b	• WHEN EXPOSED TO H_2O VAPOR CUMULATIVE NUMBER TO INCREASE MONOTONICALLY WITHOUT INFLECTION POINTS OVER 0.1% < S_C < 3.0%	• PHOTOCHEMICAL H_2SO_4 GENERATOR • STORAGE BAG	PER SPEC
A.1.c	• CONCENTRATION RANGE FROM 10^2 TO 10^3 P/CM^3 THAT ACTIVATE OVER 0.05% < S_C < 3.0%		PER SPEC
A.1.e	• SPECTROSCOPIC GRADE CHEMICALS		PER SPEC
A.3	AEROSOLS STABLE TO ± 1% FOR 15 MINUTES		GOAL (PROBABLY ACHIEVABLE USING BAG)
A.4	AEROSOLS STABLE WITHIN ± 5% FOR EXPTS. SEPARATED BY ≤ 45 MINUTES		GOAL (PROBABLY ACHIEVABLE USING BAG)
A.5	ACCEPT ADDITIONAL GENERATOR WITH CAPABILITY TO MIX PARTICLES	DESIGN OF FLUID SUBSYSTEM	PER SPEC
A.2	MONODISPERSE DISTRIBUTION, $\sigma_r \le .2r$ OVER 0.01 μM ≤ MEAN RADIUS ≤ 0.1 μM	TSI MODEL 3071 CLASSIFIER	SIZE: 0.005 - 0.15 μM CONC: 100μ GMS/M^3
A.1.d	BOLTZMANN CHARGE DISTRIBUTION	TSI MODEL 3077 NEUTRALIZER	PER SPEC
B	AEROSOL INJECTION UPSTREAM AND DOWNSTREAM OF SATURATOR	DESIGN OF FLUID SUBSYSTEM	PER SPEC
C.1	GROWTH POTENTIAL • REMOVE PARTICLES < 0.01 μM TO < 100 P/CM^3	TSI MODEL 3040 DIFFUSION BATTERY	PER SPEC
C.2	• PROVIDE SIMILAR ± 5% AEROSOL ANY TIME	REQUIRES REPRODUCIBLE GENERATOR	GOAL

TRW SYSTEMS GROUP

The table on the facing page provides an overview of the aerosol counter subsystem in terms of how the TRW design complies with the Level 1 Specification requirements.

AEROSOL COUNTER SUBSYSTEM
REQUIREMENTS AND PERFORMANCE

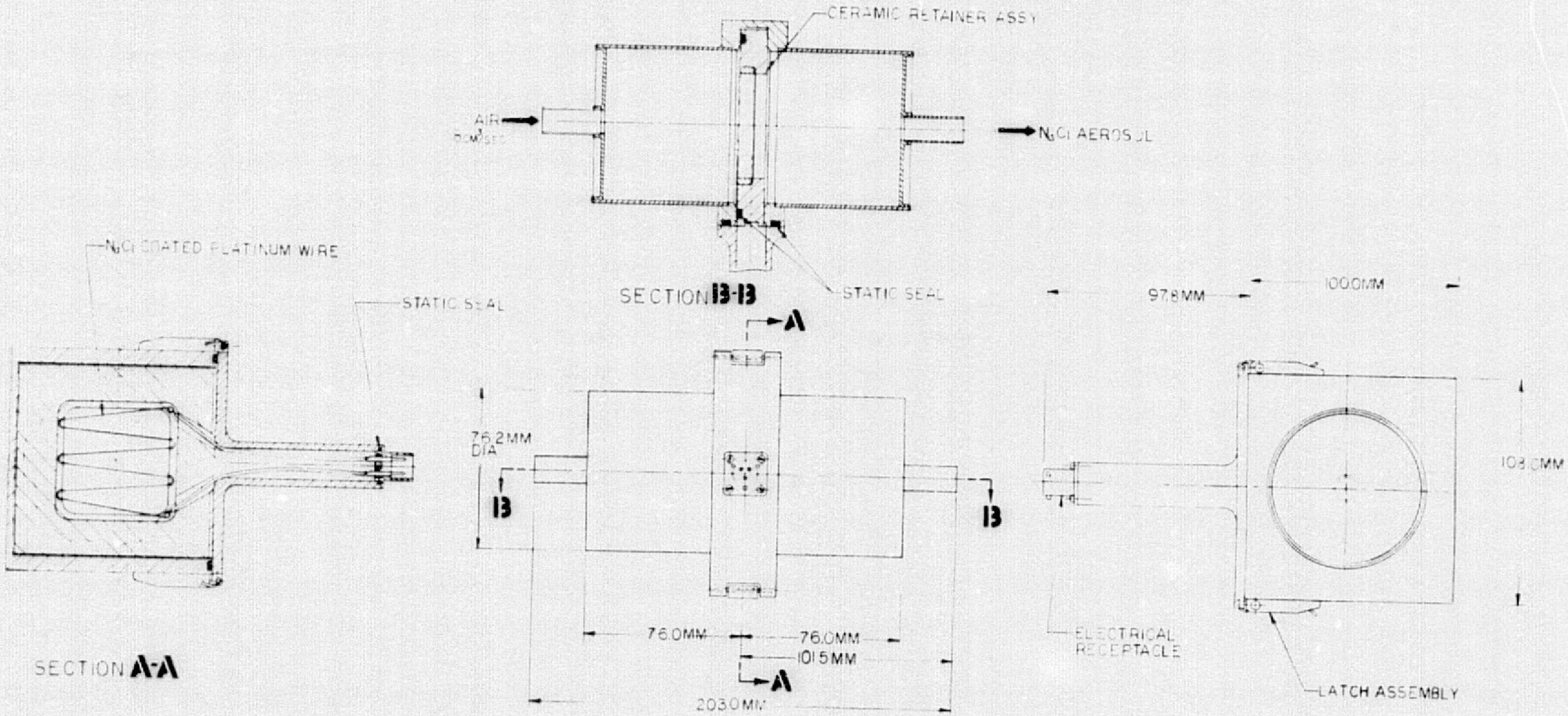
LEVEL I SPEC. PARA. 3.1.6.4	REQUIREMENT	APPROACH	PERFORMANCE
A.1 A.1.a A.1.b A.1.c	CAPABILITY TO COUNT PARTICLES WITH: • RADII > 0.001 μM • RADII 0.01 - 0.1 μM, 4 EQUAL, DISCRETE CHANNELS, X 2 ACCURACY • RADII 0.1 - 1.0 μM, 4 EQUAL, DISCRETE CHANNELS, X 2 ACCURACY	TSI MODEL 3030 ANALYZER PLUS SDL AS AITKEN COUNTER	o SIZE: 0.0016– 0.5 μM o 10 PROGRAMMABLE SIZE CATEGORIES (4 PER DECADE) o CONC: 1-10 μGMS/M^3 o TOTAL AITKEN COUNT
A.2	CAPABILITY TO COLLECT AND STORE PARTICLES FOR ELECTRON MICROSCOPE ANALYSIS	TSI MODEL 3100 SAMPLER	SIZE: 0.01 - 5.0 μM CONC: TO 10^4 μGM/M^3
A.3	CAPABILITY TO COUNT PARTICLES AND DETECT GASEOUS CONTAMINANTS EXITING AIR CLEANING SUBSYSTEM	PHOTOCHEMICAL CONVERSION PLUS AITKEN COUNT WITH SDL	PER SPEC
A.4	COUNT DROPLETS (0.15 - 5.0 μM) EXITING CFD WITH 1% COUNTING ACCURACY AND ≥ 5 CHANNELS FOR SIZE DISTRIBUTION	ROYCO MODEL 225	SIZE: 0.15 - 5 μM 5 CHANNELS SIZE ACCURACY: ± 5% COUNT ACCURACY: ± 1%
A.5	CAPABILITY TO RETURN 0.5 STD. LITER OF CLEAN AIR. STORAGE ENVIRONMENT WITHIN ± 20% STD. SEA LEVEL PRESSURE AND 5 - 35°C.	0.5 LITER SAMPLE VOLUME	PER SPEC EXCEPT STORAGE BETWEEN 5 - 50°C
B	GROWTH POTENTIAL: • CONDENSATION NUCLEI COUNTER	G.E. MODEL CNC-2	CONC: ≥ 10 P/CM^3

TRW SYSTEMS GROUP

The details of the NACL aerosol generator preliminary design are shown here. It's functional characteristics were described at the Concept and Interim Reviews.

AEROSOL GENERATOR SUBSYSTEM

NaCl AEROSOL GENERATOR PRELIMINARY DESIGN



EVAPORATION-CONDENSATION AEROSOL GENERATOR

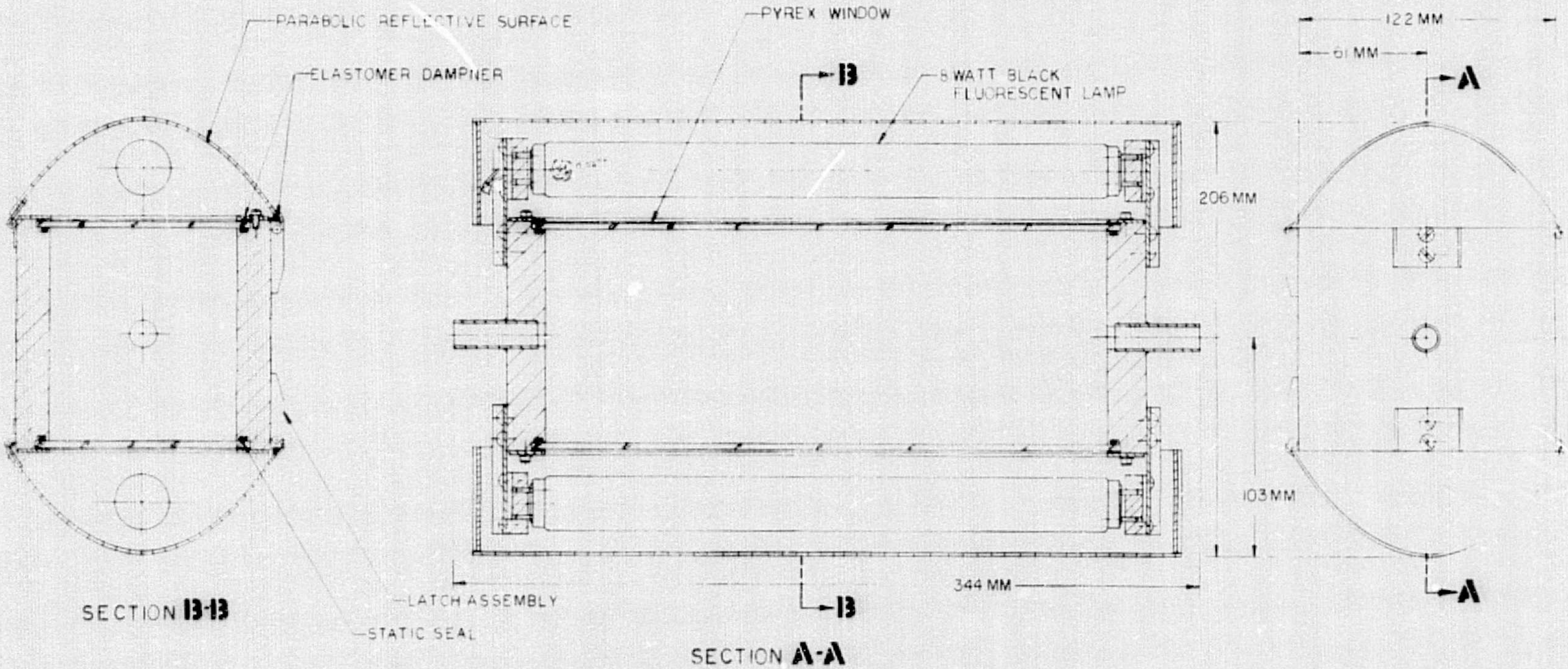
TRW SYSTEMS GROUP

The details of the H_2SO_4 generator preliminary design are shown here. It's functional characteristics were described at the Concept and Interim Reviews.

The details of the H_2SO_4 generator preliminary design are shown here. It's functional characteristics were described at the Concept and Interim Reviews.

AEROSOL GENERATOR SUBSYSTEM

H_2SO_4 AEROSOL GENERATOR PRELIMINARY DESIGN



PHOTOCHEMICAL AEROSOL GENERATOR

TRW SYSTEMS GROUP

The philosophy used with respect to commercially available hardware for the Aerosol Counter Subsystem is as shown.

AEROSOL COUNTER SUBSYSTEM

PHILOSOPHY ON THE USE OF COMMERCIAL UNITS

- RETAIN KEY FUNCTIONAL ELEMENTS OF EACH UNIT
  - ACTIVE ELEMENTS
  - SIGNAL AMPLIFIERS
  - H. V. MODULES
- D. C. POWER TO UNITS SUPPLIED BY LABORATORY
  DC TO DC CONVERTERS
- DATA PROCESSING OF ANALOG PULSES BY
  - A/D CONVERTERS (CAMAC)
  - COMPUTER
- RUGGEDIZE ACTIVE ELEMENTS AS REQUIRED, E. G.,
  - CONFORMAL COAT BOARDS AND SPOT BOND ELEMENTS
  - ELIMINATE AXIAL MOVEMENT IN MOBILITY ANALYZER
  - PROTECT OPTICAL ELEMENTS

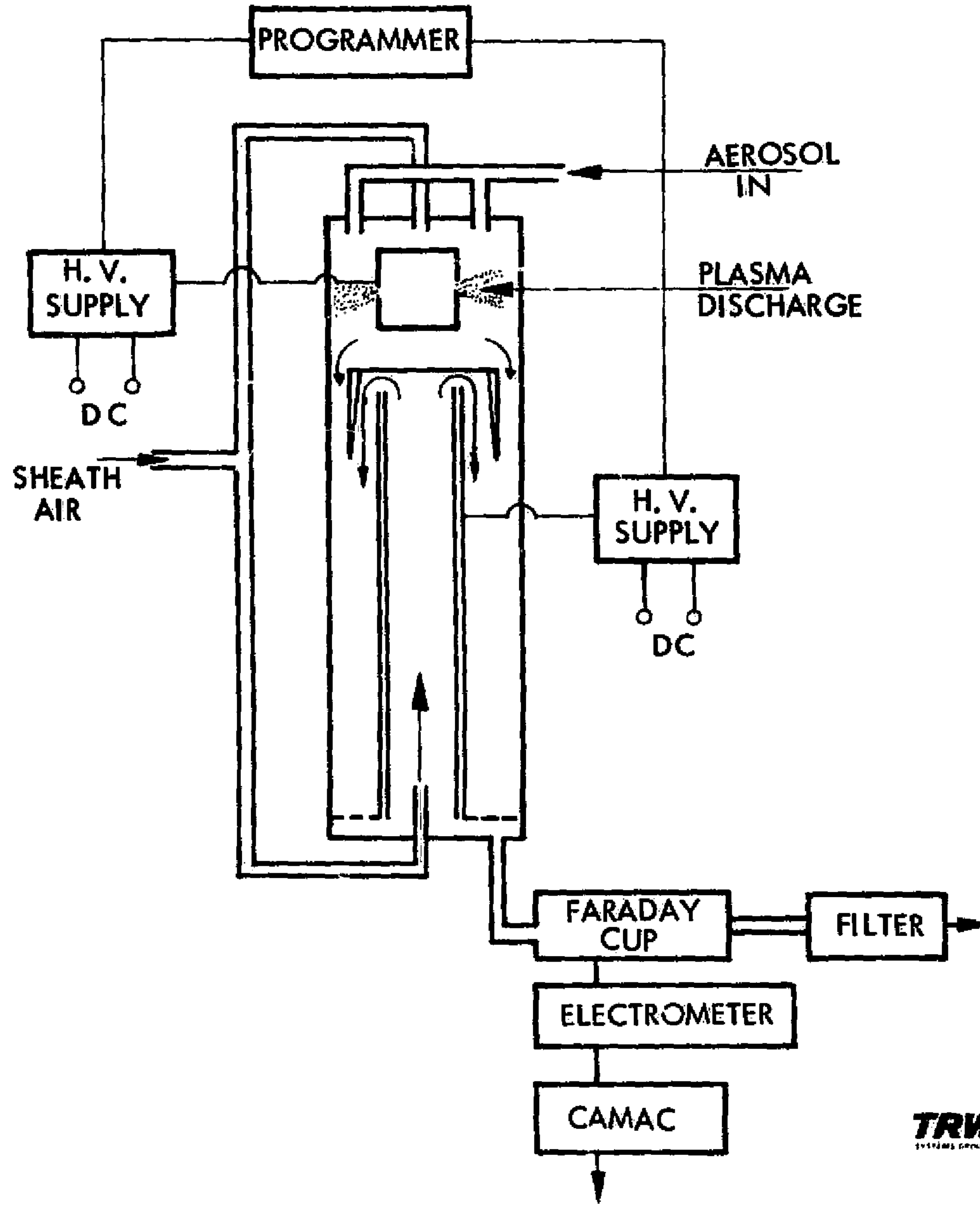
TRW

The Thermo System's Electrical Aerosol Size Analyzer Model 3030 has been selected for measurement of the aerosol size distribution. However, in order to obtain maximum benefit from the use of this unit, only the key components will be utilized. These will be repackaged to ensure efficient use of the available rack space.

AEROSOL COUNTER SUBSYSTEM

ELECTRICAL AEROSOL SIZE ANALYZER

- SELECTION
  THERMO SYSTEMS MODEL 3030
  - LABORATORY 'STANDARD'
  - EASE OF OPERATION
- SPACE LAB OPERATION WILL UTILIZE
  - CHARGER
  - ANALYZER
  - FARADAY CUP
  - FILTER
  - H. V. SUPPLIES
  - PROGRAMMER
  - ELECTROMETER



TRW

The Thermo Systems model 3071 has been selected for operation as the aerosol classifier. Although it is a new unit, it operates on a well tried principle (3030). It is compatible with the other analysis systems and Spacelab operation.

AEROSOL GENERATOR SUBSYSTEM

SIZE CLASSIFIER

SELECTION

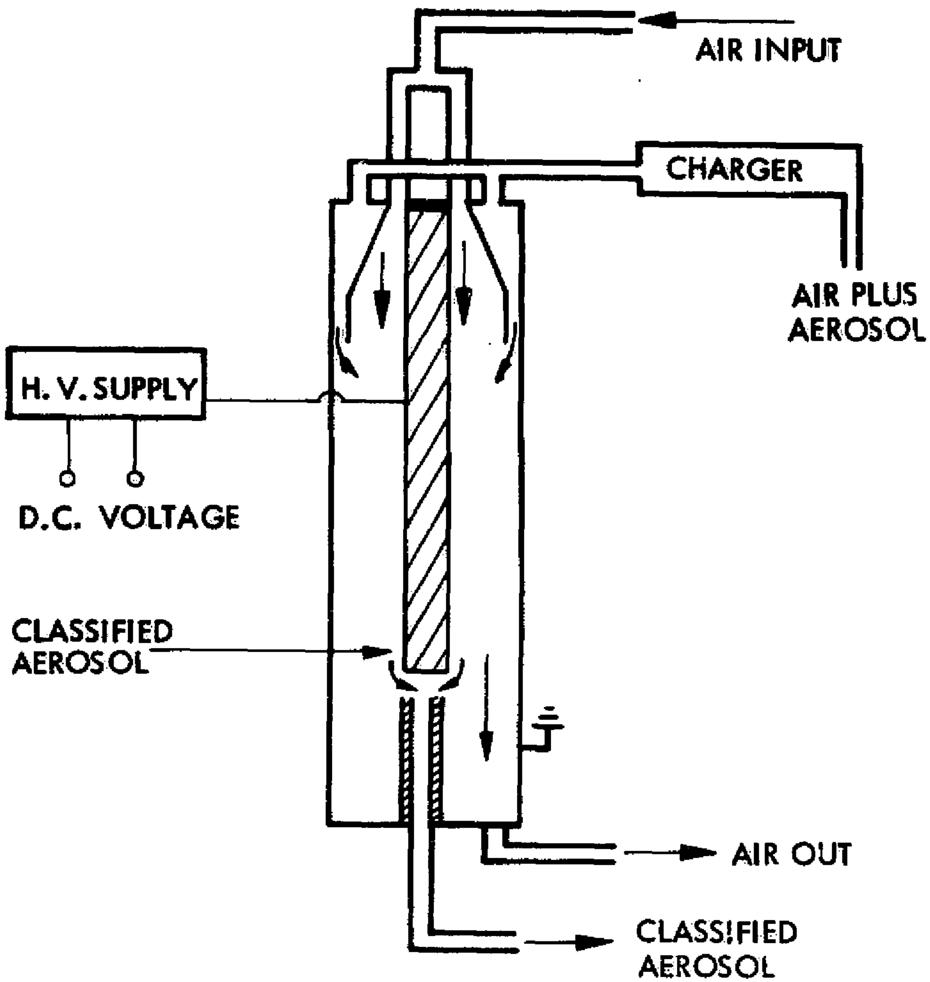
THERMO SYSTEMS MODEL 3071

- TRIED PRINCIPLE (3030)
- COMPACT UNIT
- COMPATIBLE WITH OTHER ANALYSIS SYSTEMS

APPROACH

UTILIZE

- CLASSIFIER COLUMN
- H. V. SUPPLY
- RADIOACTIVE CHARGER



TRW

Consideration of potential safety hazards led us to select an alternative radioactive source to replace the krypton gas in the TSI aerosol neutralizer.

RADIOACTIVE MATERIALS

- KRYPTON 85 USED IN TSI AEROSOL NEUTRALIZERS
- DIFFICULT TO REMOVE THIS INERT RADIOACTIVE GAS FROM SPACELAB CABIN AIR
- FAILURE OF ONE OF TWO UNITS REQUIRED FOR ACPL WOULD RELEASE A TWO MILLICURIE SOURCE
- SEVEN DAY EXPOSURE AT THIS LEVEL WOULD PRODUCE A TOTAL DOSE OF ONE RAD - ONE THIRD OF ALLOWABLE ANNUAL DOSE
- THIS UNDESIRABLE POSSIBILITY CAN BE ELIMINATED BY USE OF A METALLIC SOURCE
- FOILS OR THIN FILMS OF NICKEL 63 OR STRONTIUM 90 APPEAR TO BE GOOD SUBSTITUTES FOR KRYPTON 85 GAS
- USE OF ONE OF THESE ALTERNATIVE SOURCES IN TSI NEUTRALIZER HOUSING WOULD HAVE NEGLIGIBLE COST IMPACT

TRW SYSTEMS GROUP

The Royco Sensor unit (Model 241) has been selected for measurement of the number and size distribution of the cloud droplets exiting the CFD. This unit has been extensively used for this type of operation for many years and its operating characteristics are well understood. It is currently used with the Desert Research Institute CFD Chamber.

AEROSOL COUNTER SUBSYSTEM

OPTICAL PARTICLE DETECTOR

- SELECTION

  SENSOR UNIT (241) OF THE ROYCO MODEL 225 OPTICAL PARTICLE COUNTER HAS BEEN SELECTED FOR USE WITH THE CFD

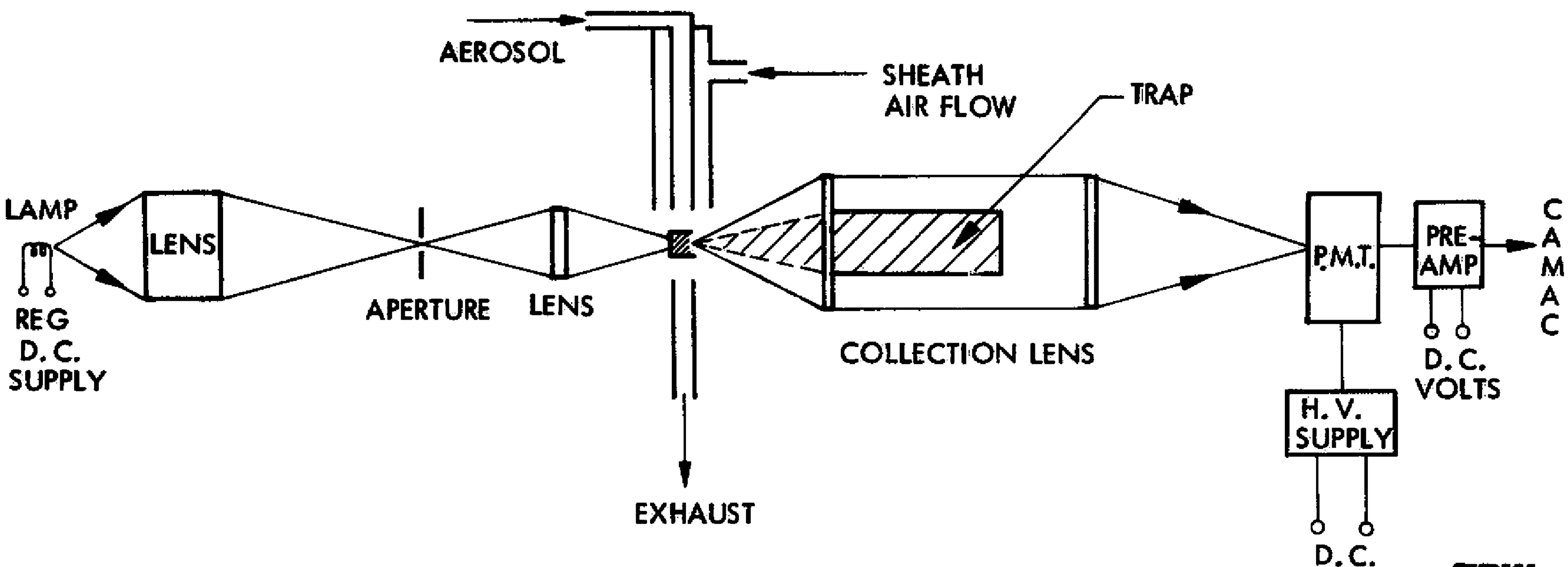
  - USED WITH THE D R I CFD CHAMBER
  - RUGGED AND COMPACT UNIT
  - PACKAGING COMPATIBLE WITH OTHER UNITS

- APPROACH

  SENSOR UNIT INCLUDES

  - OPTICS AND SAMPLE CHAMBER
  - LAMP AND P. M. T.
  - H. V. SUPPLIES
  - SIGNAL AMPLIFIER

  ANALOG BOARD FROM 225



TRW

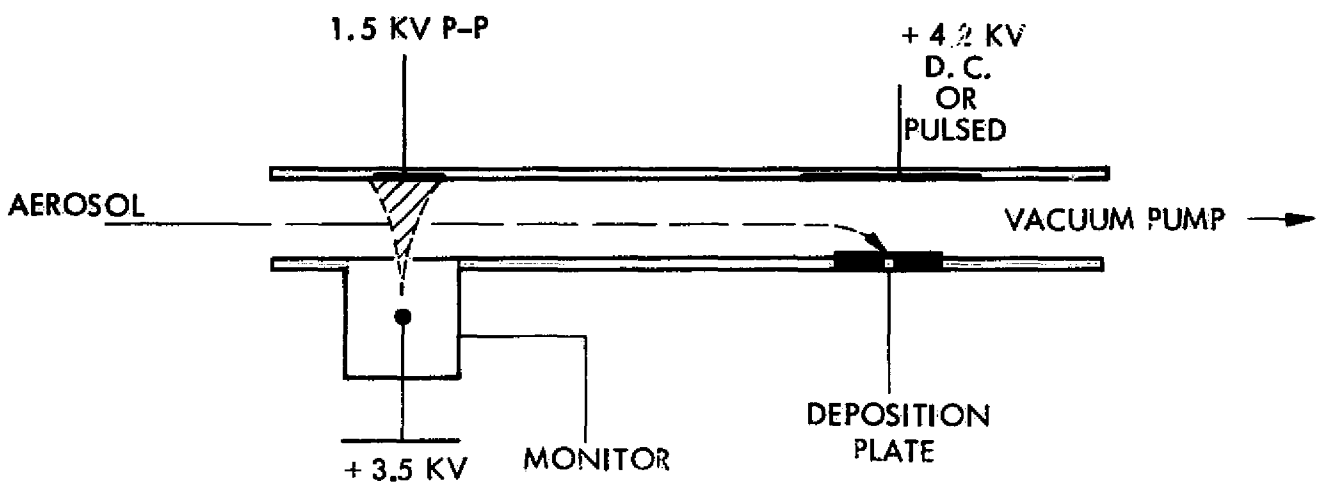
The Thermo Systems Model 3100 has been selected to provide the aerosol samples for electron microscopy. This system provides uniform aerosol samples, an important criterion for electron microscopy. It can also provide size graded samples for distribution measurements.

AERΟSOL COUNTER SUBSYSTEM

AEROSOL SAMPLER

- SELECTION
  - THE THERMO SYSTEMS MODEL 3100
    - PROVIDES UNIFORM AEROSOL DISTRIBUTION ON SAMPLE IN PULSED MODE
    - COMPACT UNIT

- APPROACH
  - FLOW CHAMBER, SAMPLE AND CONTROL PANEL USED AS IS.
  - ELECTRONIC COMPONENTS REPACKAGED
  - MECHANICAL TIMER REPLACED WITH CAMAC TIMER
  - COMPUTER CONTROL



TRW

Space has been allocated and provision made in the Fluid Subsystem for two growth items relating to aerosol generation and counting. One is a condensation nucleus counter (CNC) to provide a high sensitivity real time measurement of total CN count. This function is performed in the initial ACPL by the EAA at high particle densities and/or the SDL operated in an expansion mode. The second is a diffusion battery to serve as a high pass particle filter, removing particles $<0.01\mu$ for certain ice experiments.

AEROSOL COUNTER AND GENERATOR SUBSYSTEMS

GROWTH ITEMS

SUBSYSTEM	UNIT	FIRM AND MODEL NO.	SPACE ALLOCATED FOR UNIT	FUNCTION
COUNTER	CONDENSATION NUCLEI COUNTER	GENERAL ELECTRIC No. CNC-2	✓	HIGH SENSITIVITY PARTICLE COUNTER $\sim 10\ P/CM^3$
GENERATOR	DIFFUSION BATTERY	THERMAL SYSTEMS No. 3040	✓	HIGH PASS FILTER

TRW

OPTICAL AND IMAGING SUBSYSTEM

PRECEDING PAGE BLANK NOT FILMED

TRW

The comparison of requirements versus performance for the Optical and Imaging Subsystem on the facing page shows the preliminary design meets all Level I Specifications.

OPTICAL AND IMAGING SUBSYSTEM
REQUIREMENTS AND PERFORMANCE

REQUIREMENT	PERFORMANCE
• PHOTOGRAPH DROPLET CONCENTRATIONS FROM 100 TO 1000 PER CM^3	DESIGN COMPLIES
• DETECT DROPLETS WITH $\geq 2\mu M$ RADII	DESIGN COMPLIES
• FRAMING RATES: SINGLE PHOTOGRAPHS 3/SEC FOR 20 SEC 1/SEC FOR 250 SEC	DESIGN COMPLIES: MANUAL OR COMPUTER CONTROL
• DETERMINE NUMBER CONCENTRATION IN EXP. CHAMBER SEV TO ± 3% ACCURACY	DESIGN COMPLIES
• SEV VOLUME IN SDL $\geq$ 0.1 CM^3	SEV VOLUME UP TO 0.62 CM^3
• ELIMINATE UV AND IR THAT ADVERSELY AFFECT THE EXPERIMENTS	DESIGN COMPLIES
GROWTH POTENTIAL	
• DETERMINE CONCENTRATION OF ICE CRYSTALS IN A 1 LITER VOLUME	2 X 25 CM ILLUMINATION WINDOWS COMPATIBLE WITH 1 LITER SEV
• TECHNIQUES FOR PARTICLE SIZING: STUDY CLOUD SCATTER AND ATTENUATION OF VISIBLE, UV AND IR RADIATION; ATTENUATION AND SCATTERING MEASUREMENTS WITH MONOCHROMATIC COLLIMATED LIGHT BEAM	DESIGN IS COMPATIBLE

TRW SYSTEMS GROUP

The facing page describes the Optical and Imaging Subsystem preliminary design for the Expansion Chamber.

OPTICS AND IMAGING SUBSYSTEM

EXPANSION CHAMBER OPTICS DESIGN

ILLUMINATION SOURCE IS A 15.25 CM LONG XENON FLASHTUBE WITH A 4 MM BORE

- FLASHTUBE IS CONTAINED IN A HIGHLY REFLECTING, CLOSE WRAPPED CAVITY
- FLASHTUBE IS OPERATED AT A CURRENT DENSITY OF 5300 A/CM^2 AND APPROXIMATES A 9400 °K BLACKBODY
- SPECTRAL FILTERS REMOVE RADIATION NOT IN THE USEFUL RANGE, 350 TO 700 NM.
- THE LIGHT EXITS THE FLASHLAMP CAVITY THROUGH A 15.25 CM X 3 MM ILLUMINATION SLIT

VERTICAL AND HORIZONTAL CYLINDER OPTICS ACT INDEPENDENTLY TO FORM THE ILLUMINATION BEAM

- VERTICAL CYLINDER LENS IMAGES THE ILLUMINATION SLIT ONTO THE CHAMBER EXIT WINDOW
- HORIZONTAL CYLINDER LENSES FORM A 5X MAGNIFICATION TELECENTRIC IMAGING SYSTEM
- THE WIDTH OF THE TEST REGION IS FIVE TIMES THE WIDTH OF THE ILLUMINATION SLIT
- A 3.64 MM WIDE SLIT APERTURE BETWEEN THE TELESCOPE LENSES DETERMINES THE HORIZONTAL CONVERGENCE ANGLES

A 35 MM CAMERA RECORDS THE LIGHT SCATTERED FROM DROPLETS IN THE TEST REGION

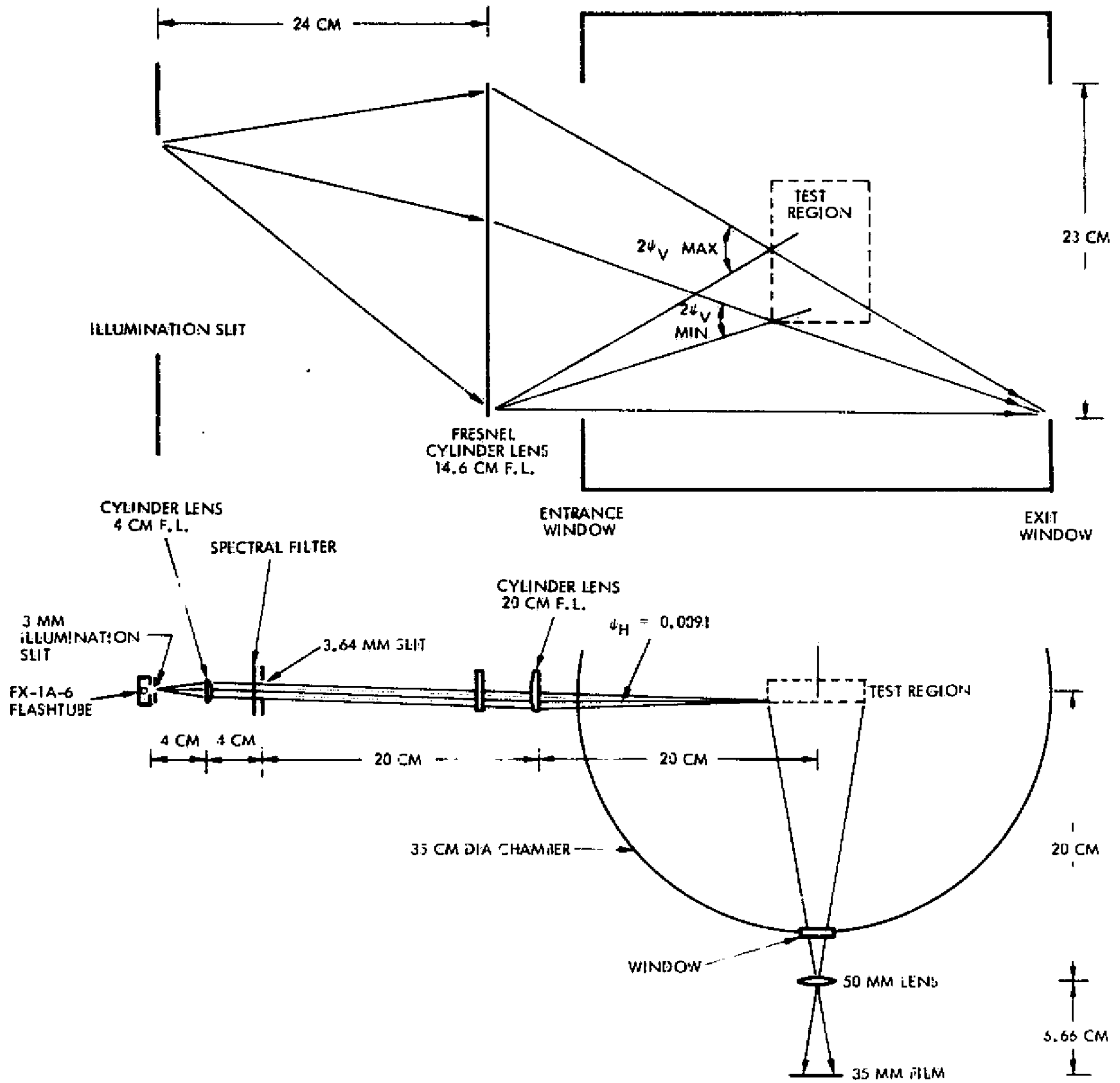
- A 50 MM CAMERA LENS IS POSITIONED TO PROVIDE 3X IMAGE REDUCTION
- A 2.6 MM CAMERA APERTURE PROVIDES A 1.5 CM DEPTH-OF-FIELD

TRW

Flashtube illumination is focused in the horizontal direction as shown on this diagram to form a 1.5 cm wide beam. The illumination beam is also focused in the vertical direction on the chamber exit window. The 35 mm camera views the beam at right angles.

OPTICAL AND IMAGING SUBSYSTEM

EXPANSION CHAMBER OPTICS SCHEMATIC



TRW

The particle density error, consisting of a volume error and a particle detection error, is calculated to be 3%.

OPTICAL AND IMAGING SUBSYSTEM

PARTICLE DENSITY ERROR

TWO COMPONENTS

- VOLUME ERROR, $\Delta V/V$
- PARTICLE DETECTION ERROR, $\Delta N/N$

ASSUMPTIONS

- THE TWO COMPONENTS ARE EQUAL BY DESIGN
- THE TWO COMPONENTS ARE INDEPENDENT

$$\text{PARTICLE DENSITY ERROR} = \Delta \rho/\rho = [(\Delta N/N)^2 + (\Delta V/V)^2]^{1/2}$$

$$= [(0.0212)^2 + (0.0212)^2]^{1/2}$$

$$= \pm 0.03$$

TRW

The facing page describes the procedure for calculating the volume error component.

OPTICAL AND IMAGING SUBSYSTEM

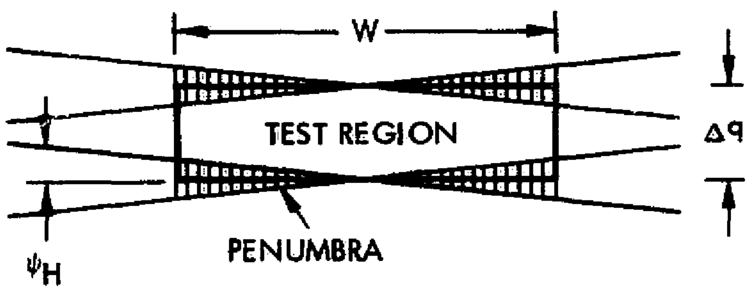
VOLUME ERROR

VOLUME ERROR RESULTS FROM TEST VOLUME THICKNESS ERROR

- PENUMBRA EFFECT
- INVERSELY PROPORTIONAL TO ILLUMINATION EFFICIENCY

$$\text{WORST CASE ERROR} = \pm\,\Delta V/V = \frac{\text{ONE-HALF PENUMBRA VOLUME}}{\text{TEST VOLUME}}$$

$$= \pm\,[W/2\,\Delta q]\ \text{TAN}\ \psi_H$$



ACTUAL ERROR DEPENDS ON DROPLET SIZE

- FOR THRESHOLD DROPLETS,

  COUNTING VOLUME = TES JME –

  ONE-HALF PENUMBRA

- FOR LARGE DROPLETS,

  COUNTING VOLUME = TEST VOLUME

  \+ ONE-HALF PENUMBRA

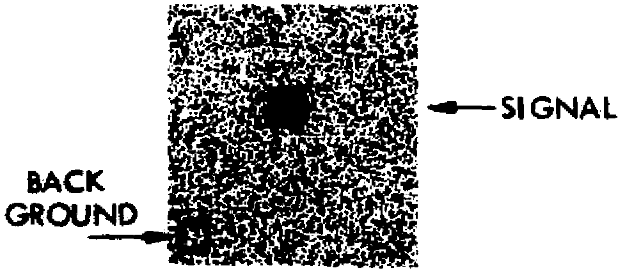
- TO MINIMIZE SYSTEMATIC ERROR, LET

  COUNTING VOLUME = TEST VOLUME = $W\Delta q$

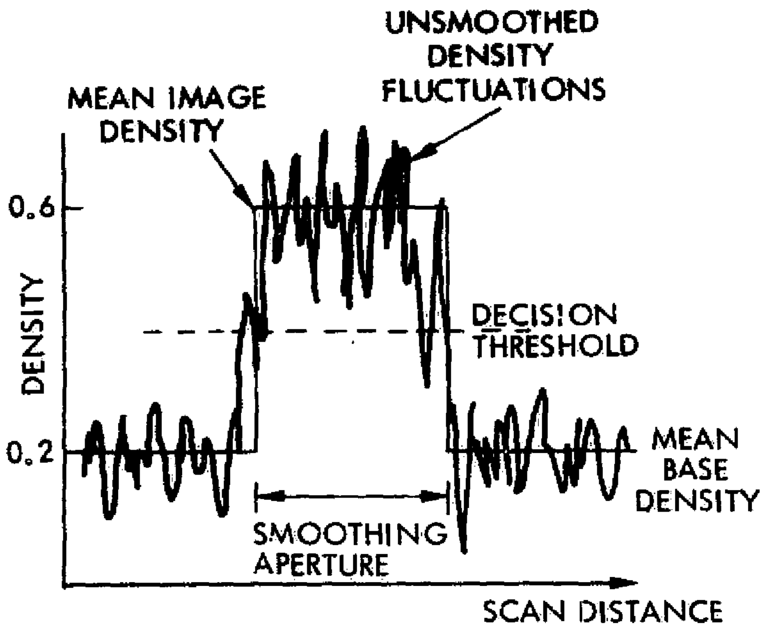
The assumptions used to evaluate the counting error in the Expansion Chamber are summarized on this facing page.

OPTICAL AND IMAGING SUBSYSTEM

COUNTING ERROR



REPRESENTATION OF A SIGNAL IN A NOISY BACKGROUND



USE A MATCHED FILTER TO MAXIMIZE IMAGE SIGNAL-TO-NOISE

- SCANNING CIRCULAR APERTURE
- A COMPROMISE SIZE IS 15 MICRON (EFFECTIVE) DIAMETER

SET DECISION THRESHOLD TO EQUALIZE ERRORS DUE TO MISSED DETECTIONS AND FALSE DETECTIONS

- FALSE DETECTION ERROR FRACTION DEPENDS ON PARTICLE DENSITY
- IMAGE SIGNAL-TO-NOISE RATIO OF 8 GIVES ALMOST CERTAIN DETECTION
- DENSITY FLUCTUATION (NOISE) $\propto$ (DENSITY)$^{1/2}$

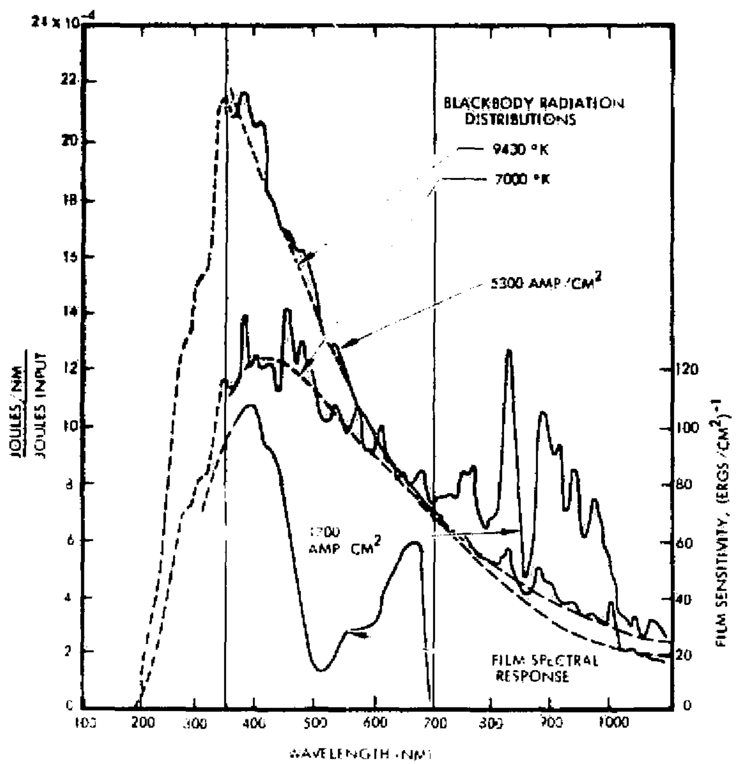
ASSUME THAT PARTICLE COUNTING ERROR DUE TO IMAGE OVERLAP CAN BE CORRECTED

TRW

The camera film used is matched to the radiation spectrum of the flashlamp to maximize energy input to the film. Filters are used to limit unwanted UV and IR radiation internal to the Expansion Chamber.

OPTICAL AND IMAGING SUBSYSTEM

FILM AND FLASHLAMP SPECTRA



SELECT FILMS WITH EXTENDED RED SENSITIZATION FOR MAXIMUM ENERGY UTILIZATION

EMPLOY FILTERS TO ELIMINATE ENERGY BELOW 350 AND ABOVE 700 NM TO MINIMIZE HEATING AND UV INDUCED REACTIONS

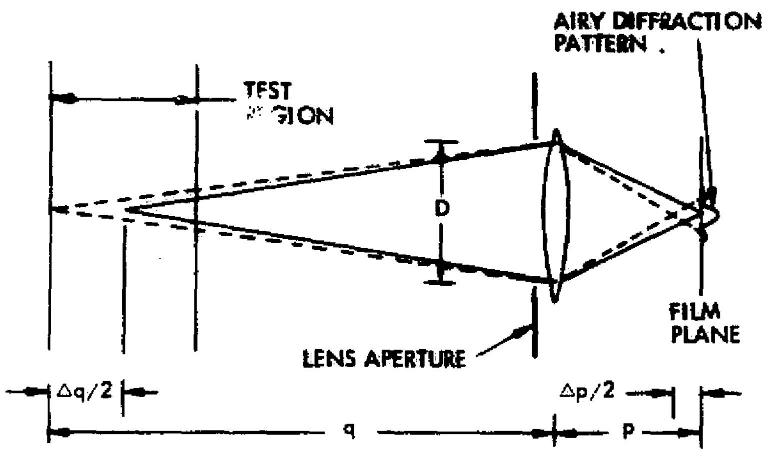
FLASHLAMP SPECTRA APPROXIMATE BLACKBODY RADIATION IN THE VISIBLE SPECTRUM

- COLOR TEMPERATURE GOVERNED BY DISCHARGE CURRENT DENSITY
- SELECT COLOR TEMPERATURE TO MAXIMIZE FILM RESPONSE

TRW

Design selection of the illumination beam thickness and camera aperture is described on this facing page.

OPTICS AND IMAGING SUBSYSTEM
DEPTH OF FIELD



DESIGN COMPROMISE
- SMALL DEPTH OF FIELD DESIRABLE FOR LIGHT GATHERING EFFICIENCY
- LARGE DEPTH OF FIELD DESIRABLE FOR OPTIMUM IMAGE DETECTION

FOCUSED DROPLETS FORM POINT DIFFRACTION IMAGES (AIRY DISC)
- IMAGE DIAMETER TO FIRST NULLS = $2.44\ \lambda\ p/D$
- IMAGE DIAMETER 10 MICRONS FOR DROPLETS UP TO 30 MICRON DIAMETER USING 2.6 MM DIAMETER CAMERA APERTURE

OUT OF FOCUS DROPLET IMAGES SUFFER GEOMETRICAL SPREADING
- GEOMETRICAL IMAGE DIA (MAX) = $D\Delta p/2p$

DEFINE DEPTH OF FIELD
- DIFFRACTION IMAGE DIA = GEOMETRICAL IMAGE DIA

$$\Delta q = 5\lambda (q/D)^2$$

DESIGN RESULT,
- TEST REGION THICKNESS = Δq = 1.5 CM
- CAMERA APERTURE = 2.6 MM DIAMETER
- CAMERA APERTURE SUBTENDS A SOLID ANGLE = 0.00013 STER

TRW

With the design input to the flashlamp (26 Joules) and in the absence of background scatter, the energy deposited on the film from a 2 micron radius droplet leads to a signal-to-noise ratio of the image of 8.

OPTICS AND IMAGING SUBSYSTEM
FILM EXPOSURE

CHAMBER ILLUMINATION EFFICIENCY

- LIMITED BY BEAM COLLIMATION AND DEPTH OF FIELD REQUIREMENTS IN HORIZONTAL DIRECTION
- LIMITED BY PHYSICAL CONSTRAINTS (E.G., WINDOW SIZE) IN VERTICAL DIRECTION
- WITH 26 JOULES LAMP INPUT ENERGY, ENERGY DENSITY (MINIMUM) IN CHAMBER IS 0.004 JOULES/CM^2

DROPLET SCATTER, WATTS/STERADIAN, TOWARD CAMERA

- ILLUMINATION ENERGY DENSITY X DROPLET CROSS-SECTION $\div$ 2π

ENERGY DEPOSITED ON THE FILM

- SCATTERED WATTS/STERADIAN X SOLID ANGLE SUBTENDED BY THE CAMERA APERTURE
- FOR A 2 MICRON RADIUS DROPLET THE DEPOSITED ENERGY = 5.4×10^{-15} JOULES
  = 13,000 GREEN PHOTONS

THE PHOTON NUMBER IS GOVERNED BY POISSON STATISTICS

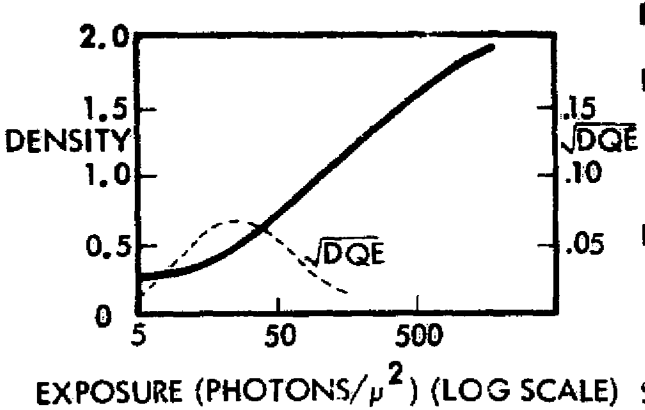
- RMS PHOTON ENERGY = $[\text{NUMBER OF PHOTONS}]^{1/2}$
- WITH NO BACKGROUND SCATTER THE SIGNAL-TO-NOISE RATIO INTO THE FILM
  $= [13{,}000]^{1/2} = 112$
- FOR A FILM DQE = 0.5%, THE SIGNAL-TO-NOISE RATIO OF THE IMAGE
  $= 112 \times [\text{DQE}]^{1/2} = 8$

TRW

Those characteristics influencing the selection of film for the Optical and Imaging Subsystem are identified on the facing page.

OPTICS AND IMAGING SUBSYSTEM

FILM SELECTION



DETECTIVE QUANTUM EFFICIENCY
OF KODAK TRI-X FILM.

DESIRABLE CHARACTERISTICS ARE:

BROAD SPECTRAL SENSITIVITY

- TO MATCH FLASHLAMP SPECTRA IN 350 TO 700 NM RANGE
- CHARACTERISTIC OF AERIAL PHOTOGRAPHIC FILMS

HIGH DETECTIVE QUANTUM EFFICIENCY (DQE)

- DQE = (OUTPUT SNR/INPUT SNR)^2
- TYPICAL VALUE IS 0.5%

SENSITIVITY TO PRODUCE AN IMAGE DENSITY OF ABOUT 0.6

- MAXIMIZES THE DQE
- THE BEST FILM IS NOT NECESSARILY THE MOST SENSITIVE
- OPTIMIZE FILM EXPOSURE FOR SMALLEST PARTICLES

TRW

The facing page describes the Optical and Imaging Subsystem preliminary design for the Static Diffusion Liquid (SDL) Chamber.

OPTICS AND IMAGING SUBSYSTEM

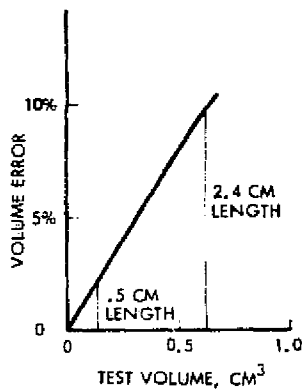
SDL CHAMBER OPTICS DESIGN

ILLUMINATION SOURCE: 3.8 CM LONG X 4 MM BORE XENON FLASHTUBE (FX-33-1.5)

- ILLUMINATES A 1 CM X 3 MM ILLUMINATION APERTURE
- LAMP IS CONTAINED IN A HIGHLY REFLECTIVE, CLOSE WRAPPED CAVITY
- LAMP CURRENT DENSITY OF 5300 A/CM^2 CREATES A 9400°K BLACKBODY

THE ILLUMINATION APERTURE IS IMAGED AT THE CENTER OF THE TEST REGION

- UNIT MAGNIFICATION TELECENTRIC IMAGING SYSTEM
- TEST REGION IS 1 CM THICK X 0.26 CM HIGH
- TEST REGION LENGTH (UP TO 2.4 CM) GOVERNS VOLUME ERROR



THE TELESCOPE APERTURE DETERMINES VERTICAL AND HORIZONTAL CONVERGENCE ANGLES

- VERTICAL ANGLE IS LIMITED BY ENTRANCE WINDOW HEIGHT (1.5 CM)
- HORIZONTAL ANGLE AFFECTS VOLUME ERROR

35 MM CAMERA RECORDS LIGHT SCATTERED FROM THE DROPLETS

- 75 MM CAMERA LENS PROVIDES 1.5X IMAGE MAGNIFICATION
- 2 MM DIAMETER CAMERA APERTURE PROVIDES NEEDED DEPTH-OF-FIELD
- 2.4 CM LONG TEST REGION IS RECORDED ON DOUBLE FRAME FILM FORMAT
- TEST REGION LENGTH CAN BE SELECTED WHEN FILM IS READ

6 JOULES INPUT TO FLASHLAMP PROVIDES 1.5 TIMES THE NUMBER OF IMAGE PHOTONS AS COMPARED TO EXPANSION CHAMBER

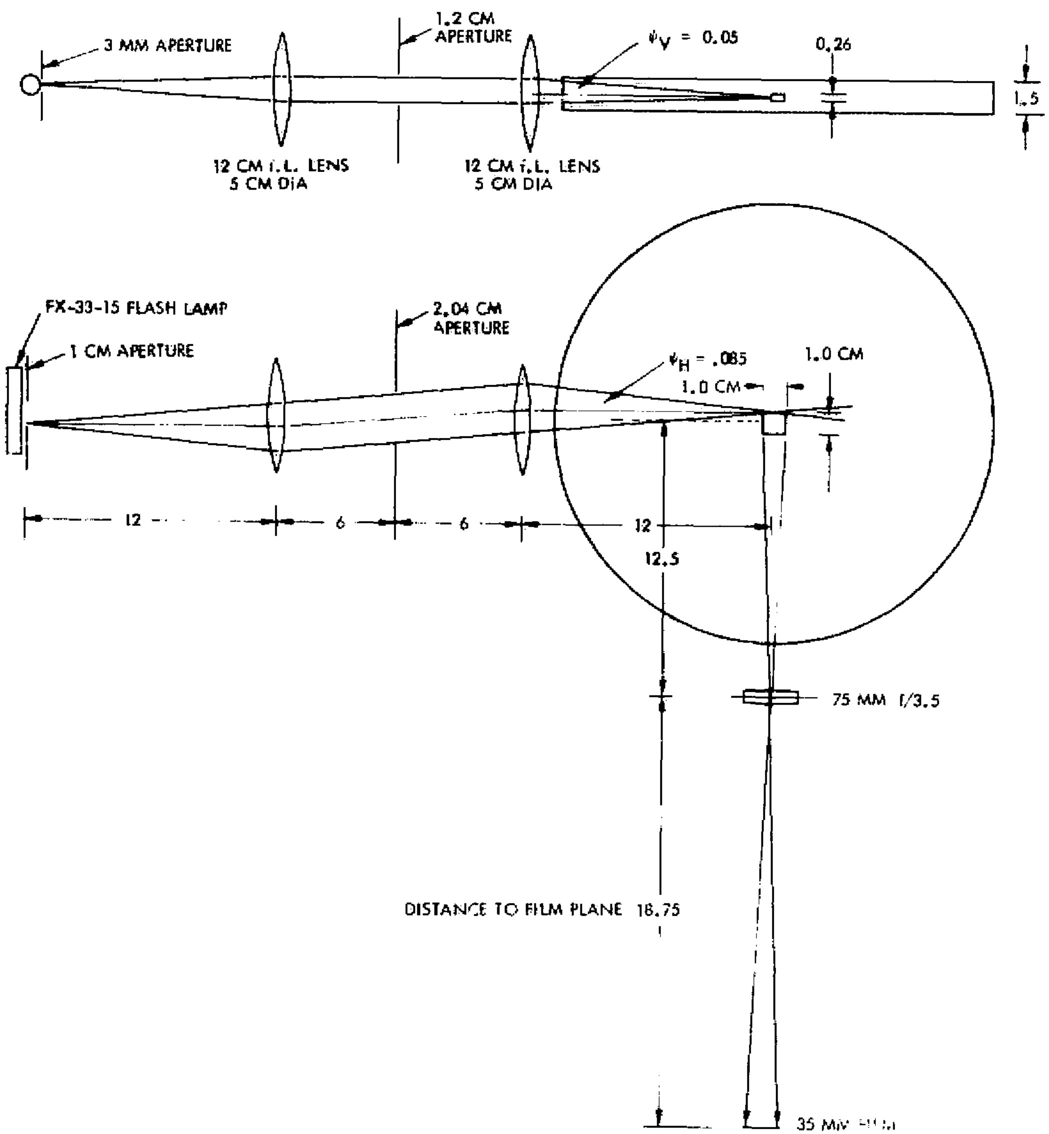
- LARGER IMAGE SIZE (57 MICRON NOMINAL) REQUIRES MORE SENSITIVE FILM TO ACHIEVE MAXIMUM DQE

TRW

The SDL optical system shown also incorporates a flashlamp, focusing optics and a 35 mm camera at right angles to the illumination beam axis.

OPTICAL AND IMAGING SUBSYSTEM

SDL OPTICAL SYSTEM



TRW

An experimental program was conducted to evaluate the electrical power requirements for the Expansion Chamber Optical and Imaging Subsystem; this vugraph identifies the tests conducted and the major results.

OPTICAL AND IMAGING SUBSYSTEM

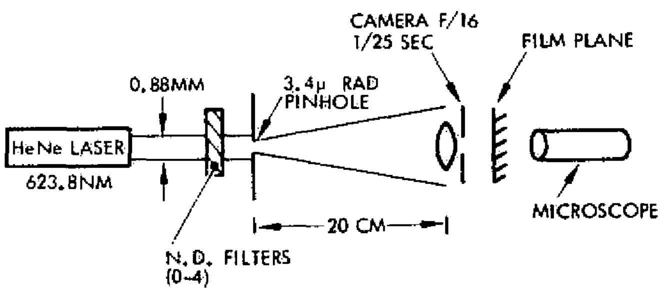
SYNOPSIS OF EXPERIMENTAL PROGRAM TO VERIFY POWER REQUIREMENT

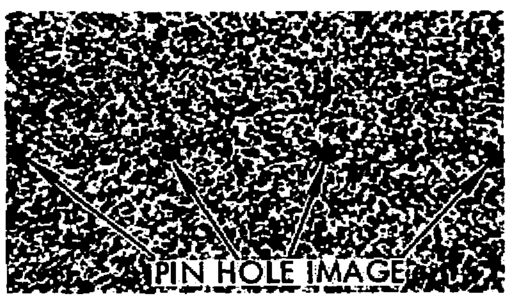
	EXPERIMENT	MAJOR RESULTS
(1)	FLASHLAMP ILLUMINATION AT DESIGN INTENSITY PHOTOGRAPHED 0.5 - 1.5 μ RADIUS QUARTZ SPHERES IN AEROSOL SPRAY	SOME PARTICLE IMAGES DEVELOPED DETECTION EFFICIENCY AND ABSENCE OF MULTIPLETS NOT EASILY VERIFIED
(2)	LASER ILLUMINATION (He - Ne) PHOTOGRAPHED 1 μ RADIUS LATEX SPHERES ON GLASS SLIDE	HIGH BACKGROUND SCATTER IMAGES CONFUSED BY SPECKLE PATTERNS
	MICROSCOPE EXAMINATION AT IMAGE PLANE	ONLY DUST PARTICLES IN AIR OBSERVABLE
(3)	LASER ILLUMINATION OF SMALL PINHOLE (He - Ne) PHOTOGRAPH PINHOLE WITH ATTENUATION FILTERS TO DETERMINE FILM SENSITIVITY AND VERIFY IMAGING SYSTEM	DETERMINED KODAK 2475 FILM DETECTIVITY TO BE 3X LOWER THAN DESIGN ANTICIPATES. MUCH OF THIS WILL BE RECAPTURED WITH OPTIMAL FILM AND MORE APPROPRIATE SPECTRAL DISTRIBUTION OF FLASHLAMP
(4)	TUNGSTEN LAMP ILLUMINATION (NBS STANDARD) PHOTOGRAPHED RANDOM PARTICLES ON FRONT-SURFACE MIRROR MICROSCOPE EXAMINATION OF MIRROR SURFACE	IMAGE OF 11 μ RADIUS PARTICLE DETECTED WITH $\leq$ 1/18 DESIGN ENERGY IRRADIATING SURFACE. INDICATES KODAK 2475 FILM WILL DETECT PARTICLES WITH 2.6 μ RADIUS AT DESIGN ENERGY AND VERIFIES SCATTERED LIGHT CALCULATIONS
(5)	XENON FLASHLAMP ILLUMINATION REPEAT OF EXPERIMENT (4)	IMAGE OF 1.5 μ RADIUS PARTICLE DETECTED WITH DESIGN ILLUMINATION INTENSITY. VERIFIES ILLUMINATOR DESIGN.

Three types of tests were conducted. The first was concerned with verification of the illumination System.

OPTICAL AND IMAGING SUBSYSTEM

VERIFICATION OF ILLUMINATION SYSTEM





PIN-HOLE IMAGED WITH N.D. = 3.3 FILTER
($1.4X10^{-14}$ JOULES)

- PIN-HOLE AND MICROSCOPE FOCUSED AT FILM PLANE. CONFIRMED THAT LENS IS DIFFRACTION LIMITED BELOW F/8
- LASER BEAM POWER KNOWN
- POWER THROUGH PIN-HOLE KNOWN
- IRRADIANCE AT LENSE IS KNOWN ($\sim 1X10^{-8}$ W/CM2 WITH NO N.D. FILTER)
- NEUTRAL DENSITY FILTERS INSERTED IN LASER BEAM VARIES IRRADIANCE AT LENS
- PICTURES TAKEN WITH F/16 AT 1/25 SEC. USING KODAK 2475 FILM
- MAXIMUM N.D. VALUE FOR WHICH IMAGE COULD BE DETECTED UNDER MICROSCOPE = 3.3 (NO SIGNAL PROCESSING)
- DETECTABLE IMAGE AT $\geq 1.4X10^{-14}$ JOULES
- DESIGN BASED ON $5X10^{-15}$ JOULES
- OPTIMUM FILM AND HIGHER SENSITIVITY TO XENON FLASHLAMP SPECTRUM PROMISES FACTOR OF 1.5 - 2 IMPROVEMENT

The second test series dealt with verification of the scattering calculations.

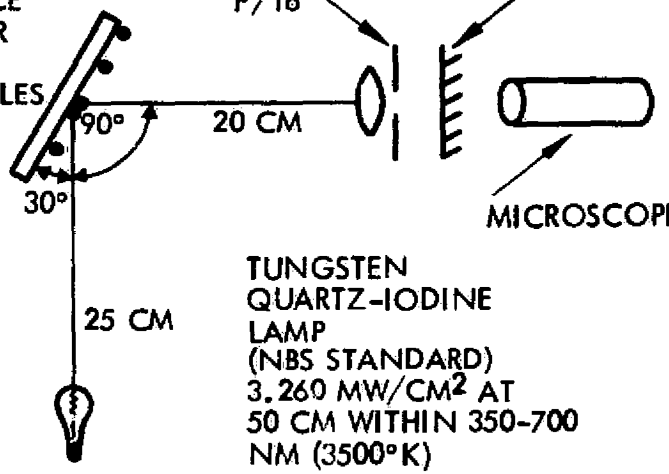
OPTICAL AND IMAGING SUBSYSTEM

VERIFICATION OF SCATTERING CALCULATIONS

FRONT SURFACE MIRROR WITH PARTICLES

CAMERA F/16

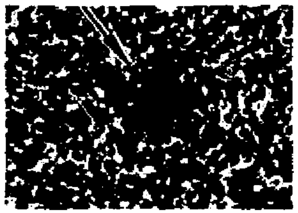
FILM PLANE



MICROSCOPE

TUNGSTEN QUARTZ-IODINE LAMP (NBS STANDARD) 3.260 MW/CM^2 AT 50 CM WITHIN 350-700 NM (3500°K)

IMAGE OF 10μ RADIUS PARTICLE



PHOTOMICROGRAPH OF PICTURE TAKEN WITH TEST APPARATUS AT F/16, 1/60 SEC

10μ RADIUS PARTICLE

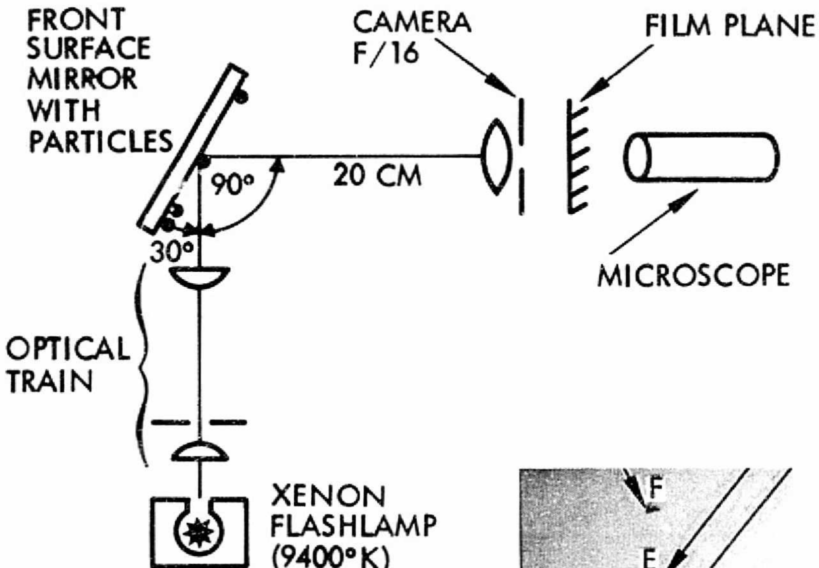
PHOTOMICROGRAPH OF MIRROR SURFACE

- STANDARD TUNGSTEN QUARTZ-IODINE LIGHT SOURCE PROVIDES KNOWN ILLUMINATION AT MIRROR: 13.40 MW/CM^2
- DESIGN ENERGY (.004 JOULE/CM^2) DEPOSITED AT SURFACE IN 0.31 SECOND
- PICTURES TAKEN WITH EXPOSURE TIMES FROM 0.004 - 1.0 SECONDS USING KODAK 2475 FILM.
- CORRELATED PICTURES WITH PHOTOMICROGRAPH OF MIRROR- IDENTIFIED COMMON PARTICLE (RADIUS = 11μ) BY LOCATION
- PARTICLE IMAGE VISIBLE AT 0.017 SEC EXPOSURE. NOT VISIBLE AT AT 0.008 SEC EXPOSURE
- DETECTION OF 11μ PARTICLE AT 1/18 DESIGN ENERGY IMPLIES DETECTION OF $11/\sqrt{18} = 2.6\mu$ PARTICLE AT FULL DESIGN ENERGY
- OPTIMUM FILM AND IMPROVED SENSITIVITY TO XENON FLASHLAMP SPECTRUM SHOULD IMPROVE PERFORMANCE

The third test series was concerned with verification of the imaging system.

OPTICAL AND IMAGING SUBSYSTEM

VERIFICATION OF IMAGING SYSTEM



- XENON FLASHLAMP AND ILLUMINATION OPTICAL TRAIN SET TO PROVIDE MULTIPLES OF DESIGN ENERGY PER FLASH (.004 JOULE/CM^2) AT SURFACE
- PICTURES TAKEN USING KODAK 2475 FILM
- CORRELATED PICTURES WITH PHOTOMICROGRAPH OF MIRROR. IDENTIFIED COMMON PARTICLE GROUPINGS
- MINIMUM PARTICLE RADIUS FOR WHICH IMAGE DETECTED AT DESIGN ENERGY WAS 1.5μ.
- OPTIMUM FILM AND OPTICAL SIGNAL PROCESSING SHOULD IMPROVE PERFORMANCE
- IMPROVED RESULTS WITH FLASHLAMP SYSTEM VS. TUNGSTEN QUARTZ - IODINE LAMP CORRESPONDS IN PART TO IMPROVED SPECTRAL MATCH. RESULTS SUGGEST ILLUMINATION SYSTEM SOMEWHAT MORE EFFICIENT THAN ANTICIPATED (24%).

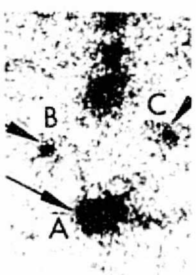


PHOTO-MICROGRAPH OF PICTURE 3X DESIGN ENERGY

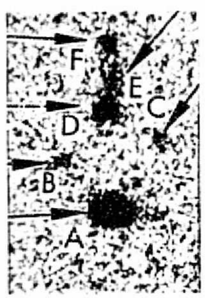


PHOTO-MICROGRAPH OF PICTURE 1X DESIGN ENERGY

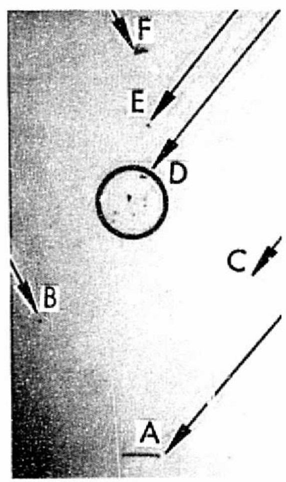


PHOTO-MICROGRAPH OF MIRROR SURFACE

OPTICAL AND IMAGING SUBSYSTEM

VERIFICATION OF IMAGING SYSTEM

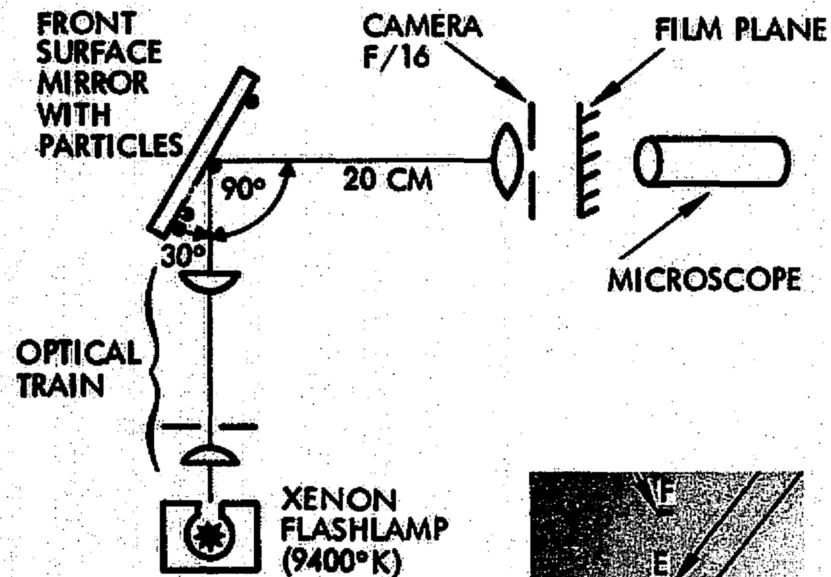


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PHOTO-MICROGRAPH OF PICTURE 3X DESIGN ENERGY

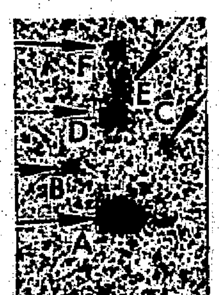

PHOTO-MICROGRAPH OF PICTURE 1X DESIGN ENERGY

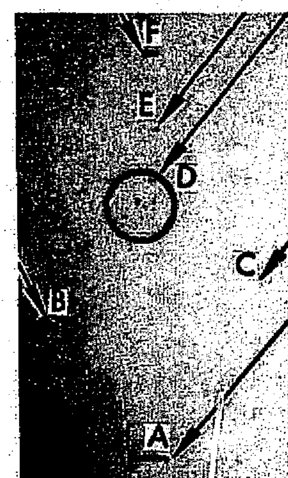

PHOTO-MICROGRAPH OF MIRROR SURFACE

In summary, the experimental results indicate that 2μ radius particles can be detected in the Expansion Chamber with ~ 26 Joules input to the flashlamp.

OPTICAL AND IMAGING SUBSYSTEM

SUMMARY OF CONCLUSIONS FROM EXPERIMENTAL PROGRAM

- IMAGE DETECTION WITH KODAK 2475 FILM REQUIRES 1.4×10^{-14} JOULES FOR He - Ne LASER LIGHT. EXPECT HIGHER SENSITIVITY FOR XENON FLASHLAMP SPECTRUM AND OPTIMUM FILM. DESIGN BASED ON 5×10^{-15} JOULES.
- LIGHT SCATTERING CALCULATIONS APPEAR FUNDAMENTALLY CORRECT BASED ON PHOTOGRAPHED PARTICLE IMAGES AT KNOWN TUNGSTEN QUARTZ-IODINE ILLUMINATION.
- XENON FLASHLAMP ILLUMINATION SYSTEM PROVIDES SOMEWHAT BETTER RESULTS THAN TUNGSTEN QUARTZ-IODINE ILLUMINATOR (CAN IMAGE 1.5μ VS. 2.6μ RADIUS PARTICLES).
- EXPERIMENTAL DATA CONSISTENT WITH ANALYTICAL PREDICTIONS.
- EXPERIMENTAL RESULTS INDICATE THAT 2μ RADIUS PARTICLES ARE DETECTABLE WITH ~ 26 JOULES INPUT TO FLASHLAMP, AS CALCULATED.

TRW SYSTEMS GROUP

SUPPORT SUBSYSTEMS

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FLUID SUBSYSTEM

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SYSTEMS GROUP

The Fluid Subsystem schematic is shown on the facing page. This is basically the Interim Review schematic redrawn. Changes to the Fluid Subsystem since Interim Review are:

1) Addition of a heat exchanger downstream of the recirculating pump to remove heat transferred to the air by the pump.

2) Addition of a R. H. meter to monitor the humidity of the air leaving Plenum 1 (controlled by adjusting cabin bleed rate).

3) Addition of an absolute pressure measurement on the CFD.

4) Addition of a vacuum plenum (Plenum 3) to permit rapid expansion of the SDL.

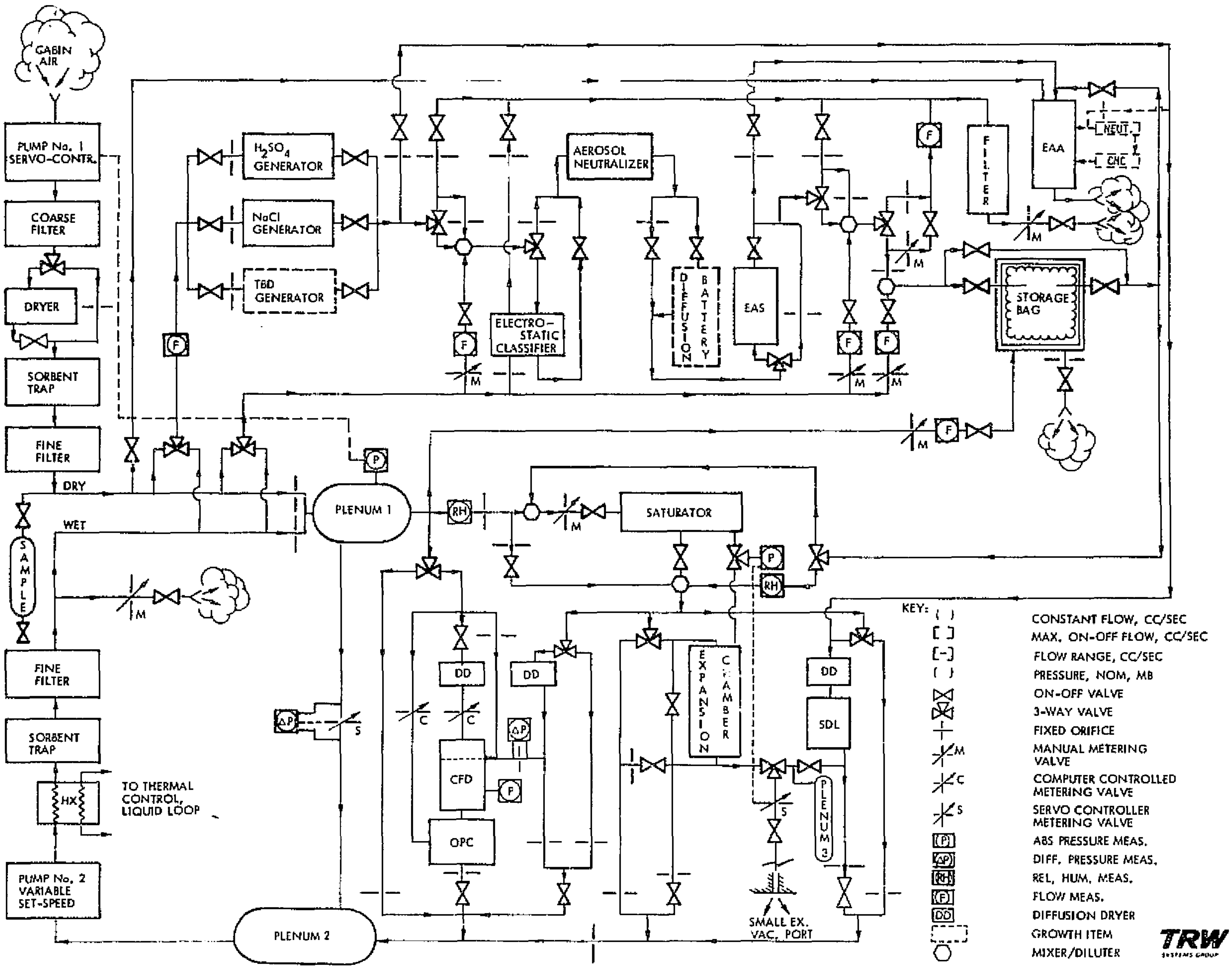
5) Moving the Electrostatic Aerosol Sampler (EAS) to the high aerosol density portion of the subsystem (downstream of neutralizer).

6) Removal of the depth filter by obtaining the CFD sample line perfusion flow from upstream of the CFD.

7) Designating the mixer/diluters as individual components instead of tees.

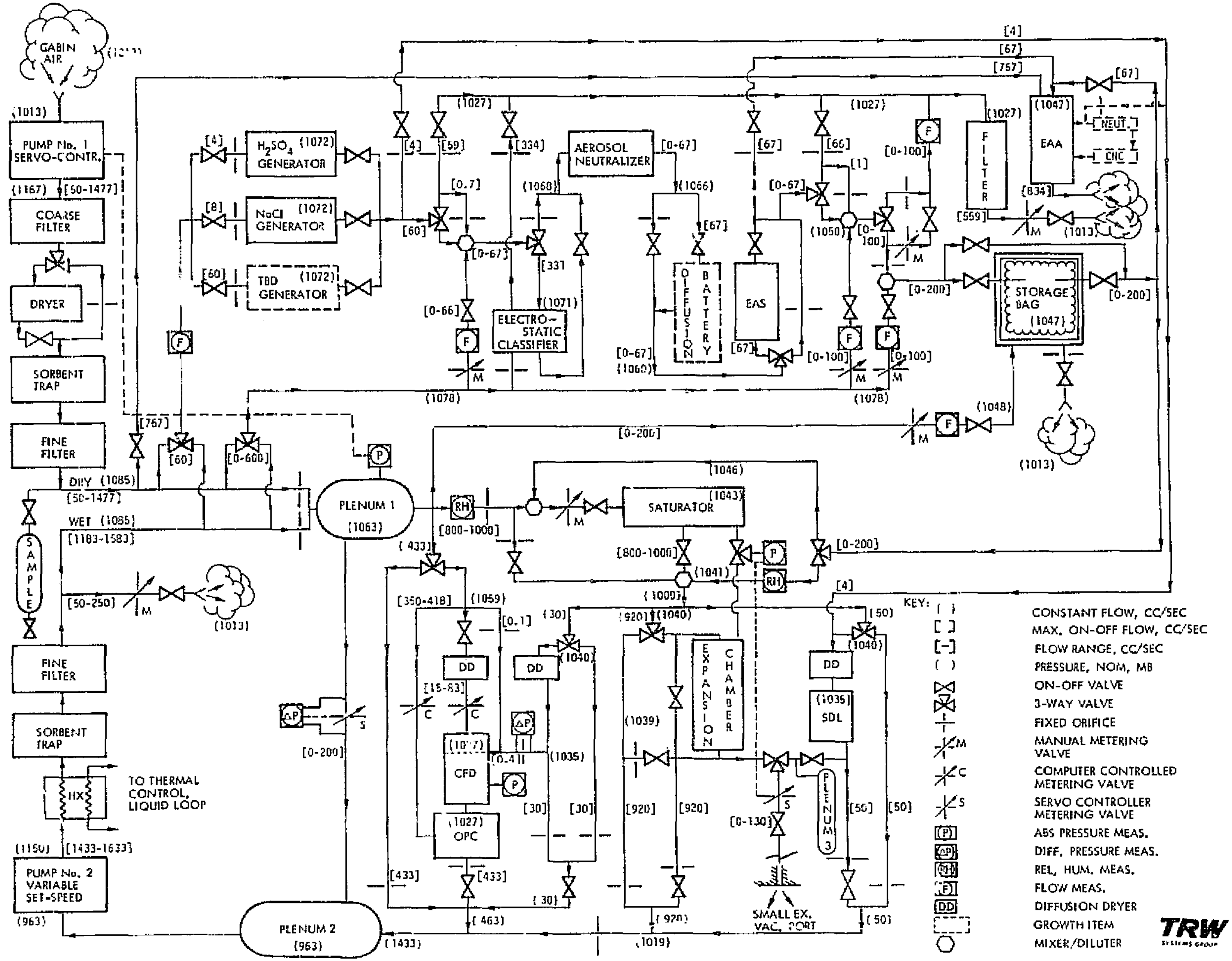
8) Inclusion of a neutralizer and CNC as growth items.

FLUID SUBSYSTEM



The facing page shows the nominal pressure and flow rate hierarchies superimposed on the Fluid Subsystem schematic. The overall subsystem pressure range is 963 to 1167 mb. The maximum subsystem flow rate is 1633 cm^3/sec.

FLUID SUBSYSTEM
PRESSURE AND FLOW HEIRARCHIES



The basic design goal for the Fluid Subsystem has been to provide proper air delivery while minimizing the number of active control elements, the manual operations required for subsystem operation, and the Spacelab Resource Requirements. This has been accomplished by means of several distinguishing features, presented on the facing page.

FLUID SUBSYSTEM
DISTINGUISHING FEATURES

	FEATURES	RESULTS
• DUAL FLOW PHILOSOPHY	- VARIABLE SPEED INLET PUMP SUPPLIES THE MAJOR INTERMITTENT FLOW DEMANDS OF THE AEROSOL CONDITIONING AND ANALYZING HARDWARE; CONSTANT SPEED RECIRCULATING PUMP SUPPLIES THE MAJOR PART OF THE CONSTANT FLOWS TO THE EXPERIMENT HARDWARE.	- MINIMIZES PRESSURE/FLOW TRANSIENTS AT THE EXPERIMENT SUBSYSTEMS DUE TO INTERMITTENT OPERATION OF THE SUPPORT SUBSYSTEMS - MINIMIZES DESICCANT AND SATURATOR LOADING
• PRESSURE DIVIDER NETWORK OPERATION	- CONSTANT FLOWS TO THE EXPERIMENT SUBSYSTEMS THROUGH FIXED RESISTANCES BETWEEN TWO PRESSURE CONTROLLED PLENUMS; PASSIVE BY-PASSES FOR EACH EXPERIMENT SUBSYSTEM WHEN NOT IN USE	- MINIMIZES PRESSURE/FLOW TRANSIENTS INTRODUCED BY INTERMITTENT OPERATION OF - THE VARIOUS SCIENTIFIC PACKAGES
• MINIMUM ACTIVE CONTROL	- ONLY THREE (3) ACTIVE CONTROL COMPONENTS: a) SERVO CONTROLLED INLET PUMP b) SERVO CONTROLLED INTER-PLENUM BLEED VALVE c) SERVO CONTROLLED EXPANSION VALVE; ALL BASED SOLELY ON TRUE PRESSURE MEASUREMENTS	- MINIMIZES SUBSYSTEM COMPLEXITY - PROVIDES GREATER ACCURACY AND CONTROLLABILITY THAN CONTROLS USING FLOW MEASUREMENTS.
• MINIMUM OPERATOR DEMANDS	- MANUAL ADJUSTMENTS LIMITED TO INITIAL SETTINGS OF THE RECIRCULATING PUMP SPEED AND THE METERING VALVES (7 TOTAL)	- MINIMIZES EXPERIMENT SET-UP TIME - REDUCES ERRORS.
• MINIMUM RESOURCE DEMANDS	- SEQUENTIALLY OPERATED LATCHING VALVES, LOW OVERALL SUBSYSTEM PRESSURE (± 2 PSI), UTILIZATION OF SMALL EXPERIMENT VACUUM PORT	- MINIMIZES AVERAGE AND PEAK POWER DRAINS - MINIMIZES PUMPING POWER

The anticipated performance of the Fluid Subsystem is compared with the Level 1 Specification requirements on the following three pages. Analysis, component specifications and analog modeling indicate that all requirements are met or exceeded.

FLUID SUBSYSTEM

REQUIREMENTS AND PERFORMANCE

LEVEL 1 SPEC. PARA. 3.1.6.1	REQUIREMENT	PERFORMANCE
A.1.	• SATURATOR SHALL SATURATE PARTICLE-FREE AND/OR AEROSOL-LADEN AIR WITH WATER VAPOR AT A PRECISELY KNOWN TEMPERATURE AND PRESSURE.	- SATURATION TO 99.99% R.H. - AEROSOL INJECTION INTO PARTICLE-FREE AIR UPSTREAM OR DOWNSTREAM OF SATURATOR. - TEMPERATURE KNOWN TO ± 0.05 °C ABSOLUTE - PRESSURE KNOWN TO ± 0.5 MB ABSOLUTE
A.2.	• SATURATOR FLOW RATE SHALL BE COMPATIBLE WITH 10 FLUSHES OF EXPANSION CHAMBER VOLUME AND SIMULTANEOUS CFD CHARACTERIZATION DURING 1000 SEC. PERIOD.	- FLOW RATE: 1000 CM^3/SEC - FLUSH TIME WITH CFD RUNNING ~ 400 SEC.
A.3.	• SATURATOR DEW POINT RANGE: 5.0 - 20°C	- DEW POINT RANGE: 5.0 - 20°C
A.4	• SATURATOR REFERENCE ZONE PRESSURE: ABSOLUTE ACCURACY ± 1.0 MB RELATIVE ACCURACY ± 0.1 MB 1000 SEC. STABILITY ± 0.5 MB	- ABSOLUTE ACCURACY ± 0.5 MB - RELATIVE ACCURACY ± 0. . MB - 1000 SEC. STABILITY ± 0.1 MB
A.5	• SATURATOR DESIGN SHALL CONSIDER INFLUENCE OF CAPILLARITY ON VAPOR PRESSURE IN REFERENCE ZONE.	- VAPOR PRESSURE REDUCTION BY CAPILLARY STRESS: < 10^{-4}%
A.6	• NO STAGNATION IN THE WATER SURFACE IN THE SATURATOR REFERENCE ZONE.	- WATER FLOW IN CAPILLARY GROOVES IN PLATE SURFACES AND FLOW FROM REFERENCE ZONE TOWARD AIR INLET ASSURE GOOD IRRIGATION OF REFERENCE ZONE WITH NO STAGNATION.
A.7	• SATURATOR WATER FLOW DEVICE CAN BE CLEANED OR REPLACED BETWEEN FLIGHTS	- MODULARIZED COMPONENT, RACK MOUNTING, AND FITTINGS PERMIT EASY REMOVAL FOR CLEANING OR REPLACEMENT BETWEEN FLIGHTS.
B.1	• NO CONDENSATION DOWNSTREAM OF SATURATOR.	- BELOW AMBIENT DEW POINTS AND CONTROL OF PRESSURE DROPS PREVENT CONDENSATION BETWEEN SATURATOR AND EXPERIMENTAL SUBSYSTEMS.

TRW

FLUID SUBSYSTEM

REQUIREMENTS AND PERFORMANCE (CONT.)

LEVEL 1 SPEC. PARA. 3.1.6.1	REQUIREMENT	PERFORMANCE
B.2.	o EXPANSION CHAMBER PRESSURE DURING STEADY STATE OPERATION: CONSTANT TO WITHIN ± 0.1 MB KNOWN TO WITHIN ± 0.5 MB ABSOLUTE KNOWN TO WITHIN ± 0.2 MB (RMS) RELATIVE TO SATURATOR REFERENCE ZONE PRESS' 'RE	- PRESSURE STABILITY ± 0.1 MB - ABSOLUTE ACCURACY ± 0.5 MB - RELATIVE ACCURACY ± 0.1 MB; RESOLUTION TO ± 0.01 MB NOMINAL
B.3.	c PARTICLE-FREE AND/OR AEROSOL-LADEN AIR DELIVERED TO EXPANSION CHAMBER: DEW POINT RANGE -20 TO + 20 °C ADJUSTABLE R.H. RANGE 50-99% WITH RESPECT TO EXPANSION CHAMBER TEMPERATURE ± 0.5% ACCURACY ON WATER VAPOR MIXING RATIO FOR DEW POINTS > 5.0 °C ± 1 °C ACCURACY ON DEW POINTS < 5.0 °C	- -20 TO + 20 °C DEW POINT AIR/AEROSOL FROM SATURATOR AND BYPASS DELIVERED DIRECTLY TO EXPANSION CHAMBER - 99.99% R.H. WITHIN SATURATOR; SATURATOR TEMPERATURE WITH RESPECT TO EXPANSION CHAMBER TEMPERATURE SETS R.H. OVER 50-99% - ± 0.05 °C ACCURACY OF TEMPERATURE MEASUREMENT OVER 5.0 TO 20 °C PERMITS DETERMINATION OF MIXING RATIO TO ± 0.5% - DEW POINT ACCURACY < 5.0 °C = < ± 1 °C
B.4.	o EXPANSION CHAMBER PRESSURE: MATCHES A PRESCRIBED P VS. t CURVE TO WITHIN ± 0.5 MB SATURATOR REFERENCE ZONE/EXPANSION CHAMBER ΔP KNOWN TO ± 0.5 MB DURING ≤ 1 MB/SEC EXPANSIONS	- EXPANSION CHAMBER PRESSURE CONTROL SYSTEM PROVIDES MEASUREMENT AND CONTROL TO ± 0.5 MB ABSOLUTE; ACCEPTS COMPUTER GENERATED OUTPUT - RELATIVE ACCURACY ± 0.1 MB; SYSTEM RESOLUTION NOT AFFECTED BY ≤ 1 MB/SEC PRESSURE CHANGES
B.5.	o EXPANSION CHAMBER PRESSURE STARTING AT A DESIGN OPERATING PRESSURE BETWEEN 0.8 AND 1.2 TIMES SPACELAB AMBIENT (~ 1013 MB) CAN BE REDUCED BY 500 MB	- DESIGN OPERATING PRESSURE IS 1.03 TIMES SPACELAB AMBIENT - EXPANSIONS > 500 MB POSSIBLE; SYSTEM CONTROLLABLE OVER 100 - 1000 MB RANGE
B.6.	o EXPANSION CHAMBER PRESSURE CAN BE CHANGED AT DRY ADIABATIC RATE COMPATIBLE WITH GIVEN TABLE (REQUIRES 1.6 MB/SEC TO 0.1 MB/SEC PRESSURE DECREASE RATES).	- PRESSURE DECAY RATES CONTROLLABLE OVER 4×10^{-4} TO 3.1 MB/SEC RANGE FOR P ≥ 500 MB

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TRW

FLUID SUBSYSTEM
REQUIREMENTS AND PERFORMANCE (CONT.)

LEVEL 1 SPEC PARA. 3.1.6.1		REQUIREMENT		PERFORMANCE
B.7	•	$\frac{d^2P}{dt^2}$ IN EXPANSION CHAMBER COMPATIBLE WITH HOLDING TEMPERATURE CHANGE TO $\leq \pm$ 0.5 °C WHEN CHANGING COOLING RATES, ASSUMING DRY ADIABATIC EXPANSION (REQUIRES ± 0.26 MB/SEC^2 AS WORST CASE)	-	MAXIMUM $\left\lvert\frac{d^2P}{dt^2}\right\rvert$ OBTAINABLE IS 0.39 MB/SEC^2
B.8	•	$\frac{dP}{dt}$ IN EXPANSION CHAMBER KNOWN TO ± 1% ACCURACY FOR CHANGES OVER 50 MB RANGE AT 0.1 TO 1.0 MB/SEC RATES	-	RESOLUTION OF PRESSURE MEASUREMENT SYSTEM IS ± 0.01 MB
B.9.	•	CFD SAMPLE FLOW RATE KNOWN TO ± 1% ACCURACY	-	ΔP MEASURED ACROSS CALIBRATED ORIFICE WITH ACCURACY OF ± 0.08% IN RANGE OF INTEREST
B.10.	•	VISUALLY DISPLAY AT CONTROL LOCATION: SATURATOR REFERENCE ZONE ABSOLUTE P CFD TO SATURATOR REFERENCE ZONE ΔP EXPANSION CHAMBER TO SAT. REF. ZONE ΔP EXPANSION CHAMBER dP/dt	-	VISUAL READOUTS PROVIDED AT CONTROL LOCATION (COMPUTER)

The dew point of the sample flow to the CFD and SDL and that of the carrier flow to the CFD must be low enough to avoid condensation on cold surfaces or transient supersaturations in excess of the operating point.

Local dew point control will be provided with in-line diffusion dryers.

For the SDL, the concern is that of a moist sample passing over a dry, cool side wall near the cold plate, cooling and activating nuclei with $S_c > S_m$, and then recirculating back to the SEV before the sample stills. This potential problem can be avoided by lowering the sample dew point below the temperature of the cold plate. Under worst case conditions, this requires reducing the relative humidity of the sample from 100% to 56% with respect to the saturator temperature.

FLUID SUBSYSTEM

DIFFUSION DRIERS

- LOCAL DEW POINT DEPRESSION REQUIRED FOR SDL SAMPLE FLOW AND CFD SAMPLE AND CARRIER FLOWS TO AVOID CONDENSATION AND TRANSIENT SUPERSATURATIONS
- DEW POINT DEPRESSION WILL BE ACCOMPLISHED WITH IN-LINE DIFFUSION DRYERS
- WORST CASE FOR SDL IS AT $S_M = 3\%$, $T_H = 20°C$ AND $T_C = 11°C$.
  DEW POINT MUST BE DEPRESSED BELOW 11°C.
  FOR $T_{SAT} = 20°C$, R. H. MUST BE REDUCED TO $<56\%$.

TRW
SYSTEMS GROUP

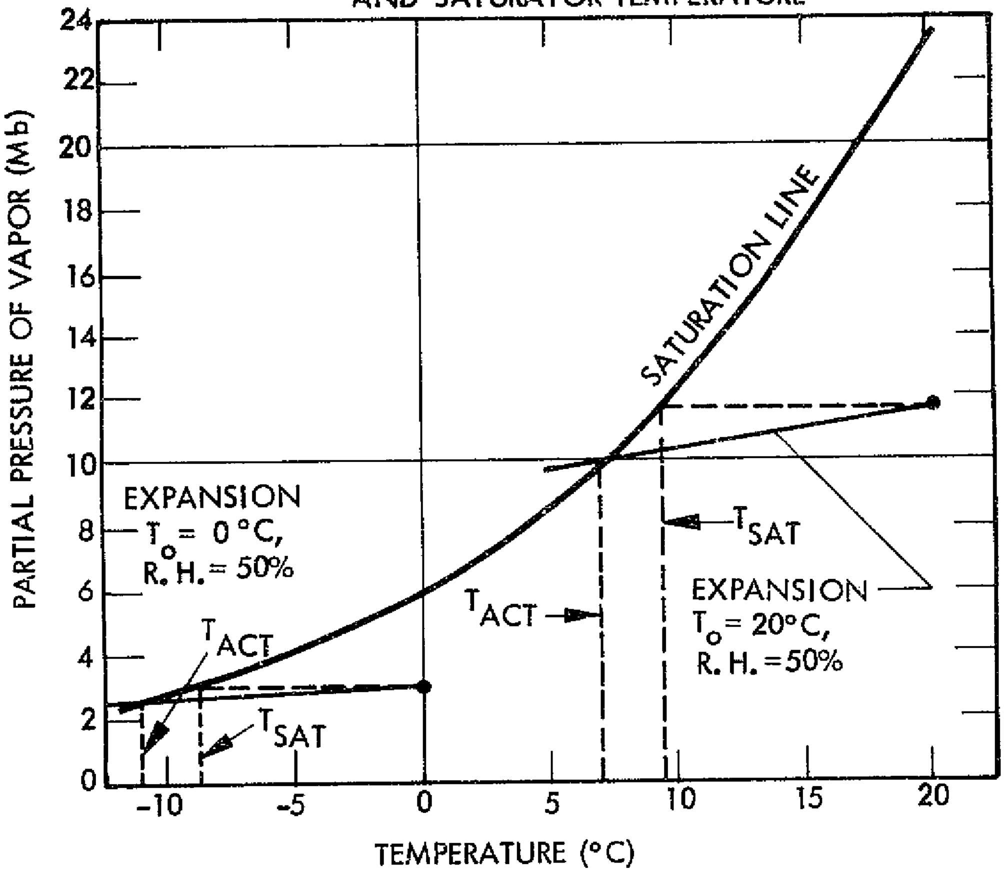
For the CFD the mean plate temperature must be at or slightly above the cloud activation temperature in the Expansion Chamber. The activation temperature is always lower than the dew point corresponding to the saturator temperature by an amount determined by the initial temperature and relative humidity prior to expansion. Thus, for most operating conditions, the sample flow must be dried to assure a dew point below the activation temperature or it will condense in the entry tube. Under worst case design conditions its relative humidity must be lowered by 15% (our design is for a 20% reduction).

The dew point of the carrier flow must be similarly reduced to avoid condensation on the hot plate at low ΔT which could yield transient supersaturations in the sample at entry. Slightly less drying is required, however, since the carrier flow is drawn from a line upstream of the saturator at a relative humidity of about 90% with respect to the saturator temperature.

FLUID SUBSYSTEM

REQUIREMENTS ON DIFFUSION DRYERS FOR CFD

RELATIONSHIP BETWEEN CLOUD ACTIVATION TEMPERATURE IN EXPANSION CHAMBER AND SATURATOR TEMPERATURE



- DEW POINT OF CFD CARRIER AND SAMPLE FLOW MUST BE $< T_{MEAN}$ $\geq T_{ACT}$
- FOR 50% R. H. INITIAL CONDITION IN EXP. CH. (WORST CASE), DEW POINT OF T_{ACT} CORRESPONDS TO 85% R. H. AT $T_{SATURATOR}$
- DIFFUSION DRYERS MUST LOWER SAMPLE FLOW R. H. FROM 100% TO <85% (DESIGN PT: 80%), AND CARRIER FLOW R. H. FROM 90% TO <85% (DESIGN PT: 77%) WITH RESPECT TO T_{SAT}

TRW

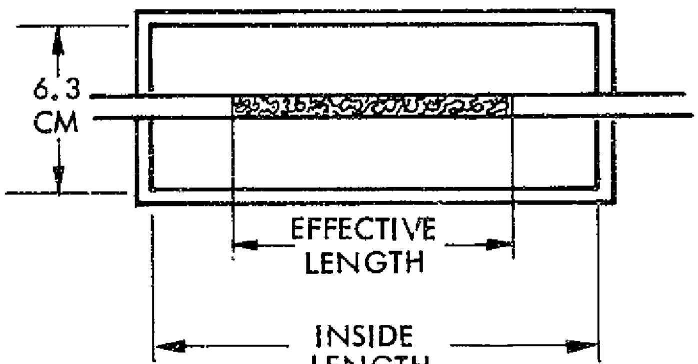
The diffusion dryers selected are modifications of a commercial unit available from Thermo-Systems, Inc. Modifications involve alterations in length, fittings and the desiccant used. Molecular sieve 13X is selected in place of silica gel because of superior properties as a desiccant.

The effective length of the diffusion drier (the length over which the air stream is exposed to the desiccant) is determined by the residence time needed to lower the humidity the required amount. The minimum inside length is determined by the radial dimensions and the quantity of desiccant needed to hold the total water to be removed per mission. The actual design length must exceed both the effective length and the minimum inside length in order to accommodate the fittings and end cap structure.

FLUID SUBSYSTEM

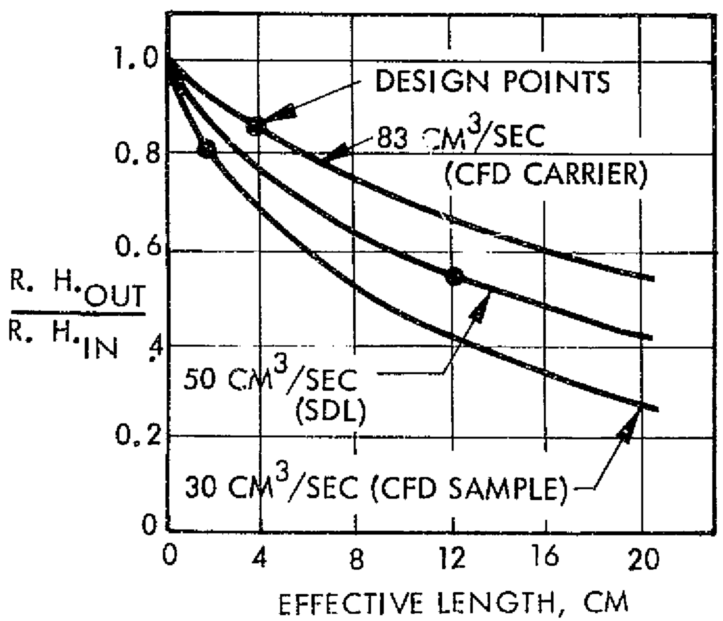
DESIGN OF DIFFUSION DRYERS

DRYER SCHEMATIC



- PERFORMANCE CALCULATIONS BASED ON TSI MODEL 3062 DIFFUSION DRYER WITH MODIFIED LENGTHS AND MOLECULAR SIEVE 13 X REPLACING SILICA GEL AS DESICCANT
- REQUIRED RH REDUCTION DETERMINES EFFECTIVE LENGTH
- REQUIRED CAPACITY (GMS H_2O REMOVED PER MISSION) DETERMINES MINIMUM INSIDE LENGTH

DRYER PERFORMANCE VS. EFFECTIVE LENGTH



SELECTED DIMENSIONS (CM)

LOCATION	EFFECTIVE LENGTH	MIN. INSIDE LENGTH	SELECTED INSIDE LENGTH*
CFD CARRIER	3.9	3.8	7
CFD SAMPLE	2.1	3.9	7
SDL	12	2.8	18

*INSIDE LENGTH MUST EXCEED REQUIRED LENGTHS TO ACCOMMODATE FITTINGS AND END CAPS

TRW

A preliminary design layout of the saturator is shown on the facing page. The saturation and reheat sections have been combined in a single package.

FLUID SUBSYSTEM
SATURATOR SUMMARY

- 3 CHANNEL SYSTEM YIELDS 99.99 PERCENT RH FOR F = 1000 CM^3/SEC WITH <0.1 mb PRESSURE DROP
- AEROSOL DEPOSITION ON WICKS HAS NEGLIGIBLE EFFECT ON MIXING RATIO
- WICK SYSTEM PROVIDES WATER STORAGE FOR ENTIRE MISSION AND IRRIGATION OF REFERENCE ZONE WITH TEMPERATURE CONTROLLED FEED WATER
- PUMPED FLUID THERMAL CONTROL SYSTEM ASSURES EQUAL PLATE TEMPERATURES, REFERENCE ZONE UNIFORMITY AND TEMPERATURE STABILITY CONSISTENT WITH REQUIREMENTS
- DESIGN MEETS ALL REQUIREMENTS AND OBJECTIVES FOR INITIAL ACPL, EXCEPT MIXING RATIO ACCURACY, AND PROVIDES GROWTH POTENTIAL

TRW SYSTEMS GROUP

Commercially available equipment has been identified for most of the Fluid Subsystem components. Most of this equipment requires little or no modification for use on ACPL. At this time, the remaining items requiring custom fabrication are:

1) Plenum 1 and Plenum 2

2) Saturator

FLUID SUBSYSTEM

IDENTIFIED COMMERCIAL EQUIPMENT

- PUMPS, INLET AND RECIRCULATING - MINOR MODIFICATIONS
- METERING VALVES, COMPUTER CONTROLLED - MINOR MODIFICATIONS
- DIFFUSION DRYERS - MINOR MODIFICATIONS
- MIXER/DILUTERS - MINOR MODIFICATIONS
- FIXED ORIFICES - MINOR MODIFICATIONS
- HEAT EXCHANGER - USE AS IS
- SOLENOID VALVES, TWO AND THREE WAY - USE AS IS
- METERING VALVES, MANUAL AND SERVO CONTROLLED - USE AS IS
- PRESSURE TRANSDUCERS, ABSOLUTE AND DIFFERENTIAL - USE AS IS
- RELATIVE HUMIDITY SENSORS - USE AS IS
- FLOW METERS - USE AS IS
- SAMPLE FLASK AND PLENUM 3 - USE AS IS
- TUBING - USE AS IS
- FITTINGS AND ADAPTERS - USE AS IS

TRW

AIR CLEANING SUBSYSTEM

The Air Cleaning Subsystem serves to remove unwanted particles and vapors, and to reduce the dew point of the inlet cabin air for low dew point operation.

Particle filtration is performed at three locations. The inlet cabin air is filtered to obtain a clean working fluid, the unused aerosol from the particle generators is filtered prior to exhausting it to the cabin, and the air in the recirculation loop is filtered to remove the injected aerosol in addition to extraneously generated particles (e.g., from the recirculation pump or sorbent trap).

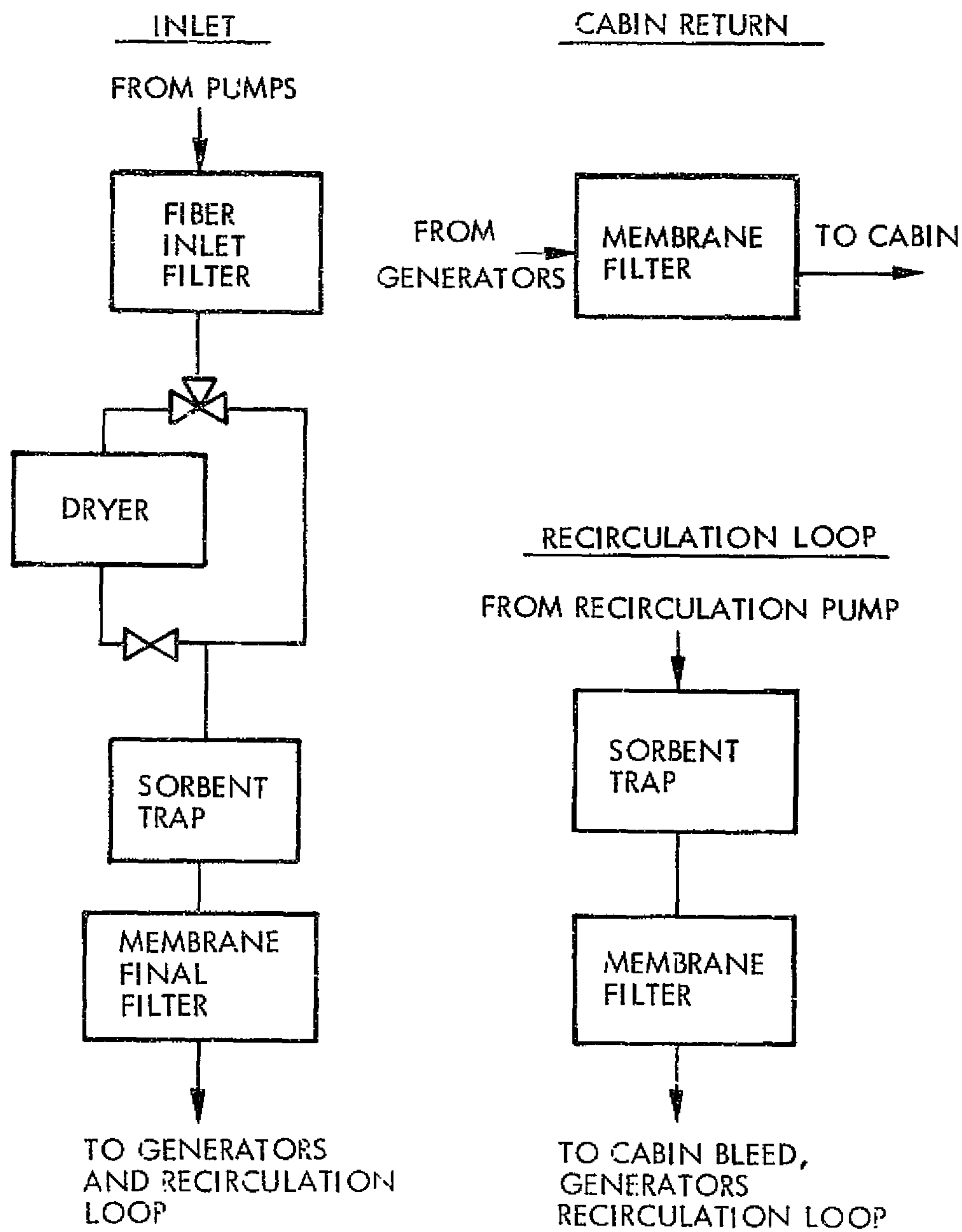
Trace gas absorption is performed in two locations. The inlet sorbent trap removes gases present in the cabin air. The recirculation loop sorbent trap removes sulfur oxides introduced with the H_2SO_4 particle generator as well as other vapors generated within the system.

Dehumidification of the cabin air is accomplished with a desiccant cannister when it is required that the dew point of the experimental air be lower than that of the cabin air.

AIR CLEANING SUBSYSTEM

DESIGN ELEMENTS

- FILTRATION
  - REMOVAL OF PARTICLES
    - INLET FROM CABIN
    - RETURN TO CABIN
    - RECIRCULATION LOOP
- ABSORPTION
  - REMOVAL OF TRACE GASES
    - INLET FROM CABIN
    - RECIRCULATION LOOP
- DEHUMIDIFICATION
  - REMOVAL OF WATER VAPOR
    - INLET FROM CABIN
    - LOW DEW POINT OPERATION



The table on the facing page summarizes the performance of the Air Cleaning Subsystem design in relation to the Level 1 Specification requirements. All of the stated requirements are met by the recommended design.

AIR CLEANING SUBSYSTEM

REQUIREMENTS AND PERFORMANCE

REQUIREMENT	PERFORMANCE
• MAX. CONCENTRATION OF PARTICLES WITH RADIUS $> 0.001\mu$ MUST BE $< 0.1/CM^3$.	• DUAL INLET FILTER EFFICIENCY $> 99.9999\%$. MEETS SPEC. FOR CABIN LEVELS UP TO 10^5 PART/CM^3. RECIRCULATION FILTER EFFICIENCY $> 99.99\%$. MEETS SPEC. FOR MAXIMUM DESIGN CONCENTRATION OF 10^3 PART/CM^3.
• DEW POINT OPERATION FROM -20 TO 20°C WITH GROWTH POTENTIAL TO -25°C.	• INLET DRYER LOWERS DEW POINT TO $<$ -30°C.
• MAX. CONCENTRATION OF ORGANIC TRACE GASES (EXCLUSIVE OF METHANE) $<$ 0.1 PPM CARBON.	• SORBENT TRAP EFFICIENCY $> 99.99\%$. YIELDS CONCENTRATION OF 0.05 PPM CARBON FOR MAX. ALLOWABLE CABIN LEVEL OF 100 PPM PENTANE EQUIVALENT.

TRW SYSTEMS GROUP

The components of the air cleaning subsystem were designed based on a total ACPL operating period of 48 hours per mission. The table on the facing page shows the assumed duty cycle, total air flow, mass removal requirements and the basis for its calculation for each of the subsystem elements.

AIR CLEANING SUBSYSTEM

CONTAMINANT AND WATER VAPOR REMOVAL REQUIREMENTS

COMPONENT	NOMINAL DUTY CYCLE	TOTAL AIR FLOW PER MISSION* (LITERS)	TOTAL MASS REMOVAL (GMS)	BASIS
INLET FILTERS	100%	50,000	< 0.1 (PARTICLES)	CABIN OPERATES AS A CLASS 100,000 CLEAN ROOM
CABIN RETURN FILTER	50%	25,000	2.0 (PARTICLES)	ASSUMED PARTICLE GENERATOR CHARACTERISTICS (WORST CASE STABLE GENERATOR)
RECIRCULATION FILTER	100%	285,000	$<10^{-3}$ (PARTICLES)	MAX. PARTICLE CONCENTRATION TO CHAMBERS
DRYER	25%	12,500	116 (WATER)	50% RH AT 22°C AVERAGE CABIN CONDITIONS
INLET SORBENT TRAP	100%	50,000	<14 (GASES)	≤ 100 PPM PENTANE EQUIVALENT IN CABIN
RECIRCULATION SORBENT TRAP	100%	285,000	10^{-3} (GASES, PRIMARILY SO_2)	H_2SO_4 GENERATOR CHARACTERISTIC

*BASED ON A 48 HOUR OPERATING PERIOD

TRW

The particle filters selected for ACPL are 0.1μ radius absolute filters, meaning that the pores will physically not pass larger particles. For particles smaller than 0.1μ radius, the principal filtration mechanisms are diffusion and interception. For these mechanisms, the combined filtration efficiency -E is given by the equation shown on the facing page where:

$$\eta = \left[1.3\ R_d\ P_e^{1/3} + 0.7\ (R_d\ P_e^{1/3})^3\right] / R_d\ P_e$$

$R_d = D_p/D_f$ (Interception Parameter)

$P_e = D_f\ V/D_b$ (Péclet Number)

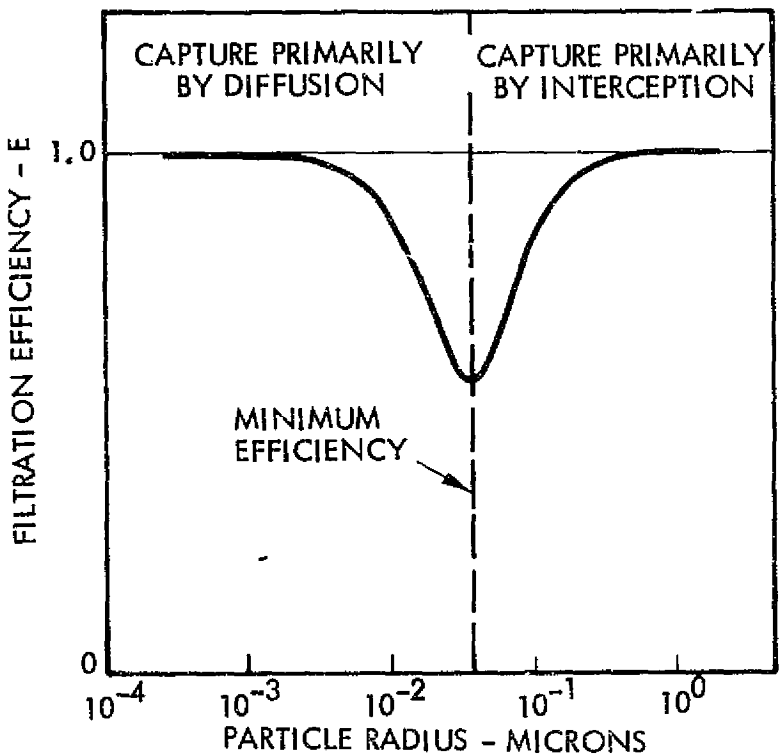
and: D_p - Particle Diameter

D_b - Particle Diffusion Coefficient

V - Face Velocity

AIR CLEANING SUBSYSTEM

PARTICLE FILTER PERFORMANCE MODEL



- SMALL PARTICLES CAPTURED BY DIFFUSION
- LARGER PARTICLES CAPTURED BY INTERCEPTION
- LARGEST PARTICLES ($>.1\mu$ FOR CHOSEN FILTERS) ARE FILTERED ABSOLUTELY; I.E., CANNOT PHYSICALLY PASS THROUGH PORES
- $$E = 1 - \exp\left[\frac{-4L\alpha\eta}{\pi D_f\ (1-\alpha)}\right]$$

L = FILTER DEPTH

α = FIBER FRACTION

D_f = FIBER DIAMETER

η = SINGLE FIBER EFFICIENCY

(FUNCTION OF PARTICLE DIAMETER, FIBER DIAMETER, DIFFUSION COEF. AND FACE VELOCITY)

- FOR A SPECIFIC FILTER AND FLOW RATE, THERE IS A PARTICLE SIZE FOR WHICH FILTRATION EFFICIENCY IS A MINIMUM.
- HIGH EFFICIENCY FOR ALL SIZES CAN BE ACHIEVED WITH MULTIPLE FILTERS HAVING DISPLACED MINIMA.

TRW

Within the expected range of parameters the analytical model yields minimum filtration efficiencies for particle radii in the range $0.03 < r_p < 0.1\mu$. In this range, the calculated efficiency is > 99.99998% for the filters selected.

Transmission (1-E) comparisons between analysis and experiment show agreement within a factor of 5, the analysis being optimistic (Kirsh, et al, Journal of Aerosol Science, March 1975).

The measured efficiency of a 0.5μ diameter absolute Millipore membrane filter (virtually identical in structure to the selected cabin return, recirculation and final inlet filter but not packaged as compactly) was found to be >99.99% for $0.015 < r_p < 0.5\mu$ (Liu and Lee, Environmental Science and Technology, April 1976).

Based on the literature and our analyses, we feel that 99.99% is a conservative estimate for the efficiency of the filters selected for particles >.001μ radius. This will meet the filtration requirements.

Membrane filters were selected for the cabin return, recirculation and final inlet filters to avoid fiber shedding problems usually associated with fiber filters. However, a fiber filter was selected for the first inlet filter to provide a variation in filtration characteristics. The two filters will have efficiency minima at different particle sizes and will compliment each other yielding a series combined efficiency >99.9999%. Any fibers shed by the first inlet filter will be removed by the final inlet filter.

AIR CLEANING SUBSYSTEM

PARTICLE FILTER PERFORMANCE

- PARTICLE SIZE CORRESPONDING TO MINIMUM E: $0.03 < r_p < 0.1\,\mu$
- CALCULATED MINIMUM EFFICIENCY - E_{MIN}: $> 99.99998\%$
- COMPARISON BETWEEN ANALYTICAL MODEL AND EXPERIMENT SHOW MODEL TO BE OPTIMISTIC BY ABOUT A FACTOR OF 5 AT THESE LEVELS
- A CONSERVATIVE ESTIMATE FOR THE EFFICIENCY OF A SINGLE FILTER IS 99.99%, SUFFICIENT TO MEET REQUIREMENTS
- TWO INLET FILTERS WITH COMPLIMENTARY CHARACTERISTICS PROVIDE A COMBINED EFFICIENCY OF $> 99.9999\%$.

TRW

Activated charcoal has been selected as the most efficient sorbent for removing organic vapors. The table on the facing page shows the calculated contaminant removal requirements based upon maximum allowable cabin air levels and a total inlet flow to ACPL of 50,000 liters per mission (48 hour operating period). Also shown is the calculated mass of activated charcoal required to provide this absorption capacity.

AIR CLEANING SUBSYSTEM

REMOVAL OF ORGANIC VAPOR FROM CABIN AIR

REMOVAL REQUIREMENTS BASED ON MAXIMUM ALLOWABLE SPACELAB CONCENTRATIONS				
CONTAMINANT CLASS	1 CAPACITY, WT %	2 EXPECTED LEVEL (MG/M^3)	3 TOTAL MASS CONTAMINANT (GMS)	MASS ACTIVATED CHARCOAL REQ., (GMS)
1. ALCOHOLS (AS METHANOL)	35-40	10.0	0.5	1.43
2. ALDEHYDES (AS AEROLEIN)	8-10	0.1	0.005	0.063
3. AROMATICS (AS BENZENE)	40-50	3.0	0.15	0.38
4. ESTERS (AS METHYL BUTYRATE)	35	30.0	1.5	4.3
5. ETHERS (AS FURAN)	20	3.0	0.01	0.75
6. HALOCARBONS				
a) CHLOROCARBONS (AS CHLOROACETENE)	15-20	0.2	0.01	0.07
b) CHLOROFLUOROCARBONS (AS CCL_2F_2	30	24.0	1.2	4.0
c) FLUOROCARBONS (AS CHF_3)	25-30	12.0	0.6	2.4
7. HYDROCARBONS (AS N-PENTANE)	30	3.0	0.15	0.5
8. KETONES (AS DIISOBUTYL KETONE)	30	29.0	1.45	4.8
9. MERCAPTANS (AS METHYL MERCAPTAN)	30-35	2.0	0.10	0.33
10. ORGANIC ACIDS (AS ACETIC ACID)	25	5.0	0.25	1.0
11. ORGANIC NITROGENS (AS MMH)	18	0.3	0.0015	0.008
12. ORGANIC SULFIDES (AS DIETHYL SULFIDE)	20	0.37	0.0185	0.093
TOTAL, ORGANICS			6.09	20.00

1. CHARCOAL SORBENT CAPACITY AT 50% RH
2. MAXIMUM CABIN AIR CONCENTRATION
3. BASED ON TOTAL VOLUME OF 50,000 LITERS

TRW SYSTEMS GROUP

The mass of activated charcoal required for removal of organics is determined not only by the organic mass to be removed (6 gms by class or 14 gms as 100 ppm pentane equivalent), but also by the shape of the cannister and residence time required to lower the concentration to 0.1 ppm carbon. For ACPL, the residence time requirement drives the design.

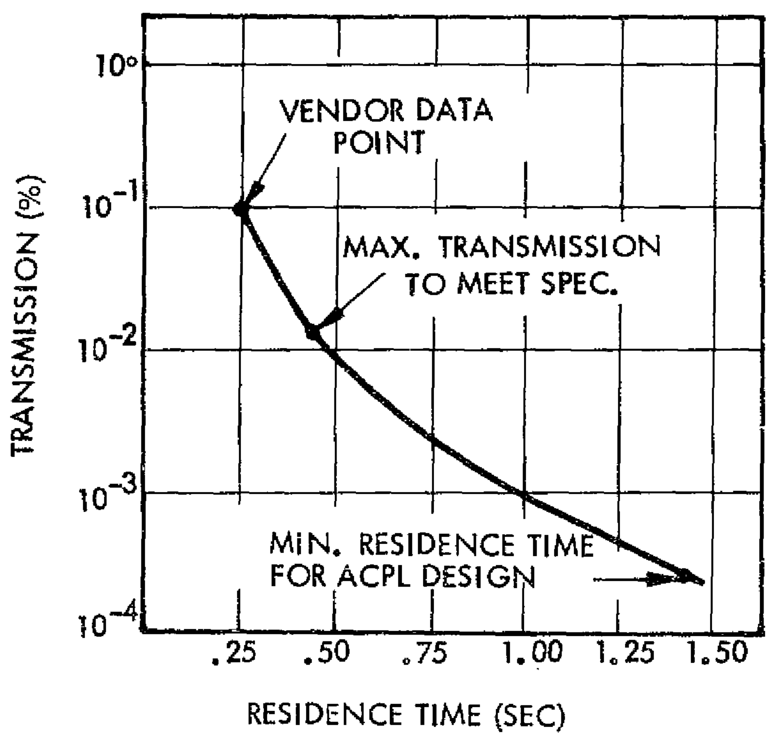
For packaging convenience, similar cannisters have been selected for the sorbent traps and dryer (10.16 cm dia. X 29.69 cm long). This cannister results in a minimum residence time of 1.45 seconds which yields a capture efficiency in excess of the 99.99% required.

Each sorbent trap holds 1.15 kg of charcoal, which will absorb approximately 8% water vapor. To avoid adverse effects on the system psychrometrics, the charcoal will be pre-saturated so that the sorbent traps are transparent to water vapor. The charcoal will be replaced between flights.

AIR CLEANING SUBSYSTEM

SIZING OF SORBENT TRAPS

ORGANIC VAPOR TRANSMISSION VS. RESIDENCE TIME



- REQUIRED MASS OF CHARCOAL DETERMINED BY:
  1) MASS OF ORGANICS TO BE REMOVED
  2) RESIDENCE TIME TO LOWER CONCENTRATION TO 0.1 PPM CARBON
- RESIDENCE TIME REQUIREMENT DRIVES DESIGN
- STANDARDIZED CANISTER PROVIDES MINIMUM RESIDENCE TIME OF 1.45 SECONDS
- CONSERVATIVE EFFICIENCY ESTIMATED AT > 99.99% AND MEETS SPECIFICATION
- 1.150 KG OF CHARCOAL USED IN EACH SORBENT TRAP
- CHARCOAL PRE-SATURATED WITH WATER

TRW

Mol Sieve 13X has been selected as the desiccant for the inlet dryer to minimize the volume of material required. 8 x 12 beads have been chosen as the form to maximize packing density and minimize particle production.

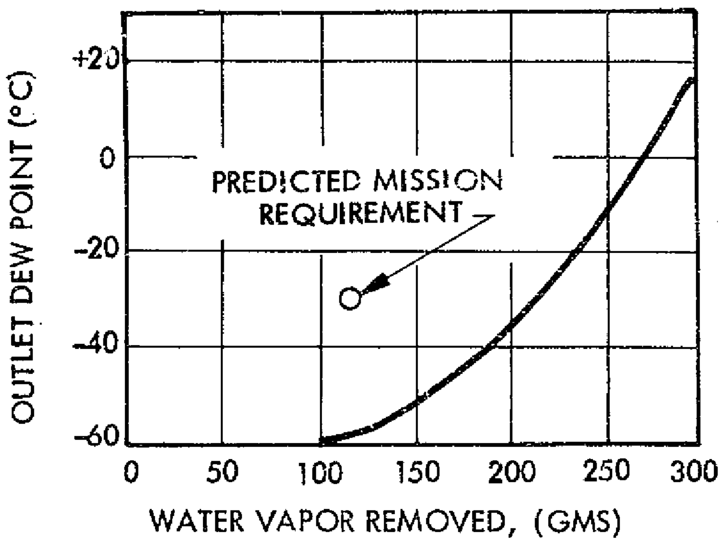
The manufacturers recommendation of 10% dynamic capacity was used to determine the quantity of desiccant required. For the required 116 gms of water vapor removal, this corresponds to 1160 gms of Mol Sieve 13X. The standardized cannister holds 1380 gms, yielding a 20% margin of safety.

Performance calculations for the selected design are shown on the facing graph. The outlet dew point, a function of face velocity, flow length and quantity of vapor absorbed, is conservatively below the required $-30^{0}C$ for an entire mission, assuming a total of 116 gms water removal as previously calculated. Such conservatism is warranted since it simplifies filling and handling procedures prior to launch.

AIR CLEANING SUBSYSTEM

INLET DRYER

DRYER PERFORMANCE
VS. WATER ABSORBED



- DESICCANT: 1380 GMS OF MOL SIEVE 13 X
- 10% DYNAMIC CAPACITY ASSUMED
- OUTLET DEW POINT < -30°C OVER ENTIRE MISSION
- LEVEL I SPEC IS MET

TRW

The facing page summarizes the design features of the Air Cleaning Subsystem.

AIR CLEANING SUBSYSTEM

SUMMARY OF FEATURES

- ALL COMPONENTS COMMERCIALLY AVAILABLE.
- MEMBRANE PARTICLE FILTERS YIELD MAXIMUM PERFORMANCE WITH MINIMUM PRESSURE DROP. A FIBER FILTER IN SERIES WITH THE MEMBRANE FILTER PROVIDES INCREASED EFFICIENCY AT THE INLET (> 99.9999%).
- ACTIVATED CHARCOAL SELECTED AS THE MOST EFFICIENT SORBENT. REQUIRED MASS OF SORBENT DETERMINED BY RESIDENCE TIME REQUIREMENTS.
- MOLECULAR SIEVE SELECTED TO PROVIDE MAXIMUM DRYING CAPACITY. REQUIRED MASS OF DESICCANT DETERMINED BY CAPACITY REQUIREMENTS.
- FILTER, DRYER AND SORBENT TRAP HOUSINGS ARE STANDARDIZED, REDUCING COSTS AND SIMPLIFYING PACKAGING.
- OTHER COMPONENTS AND MATERIALS SEEN BY THE EXPERIMENTAL AIR HAVE BEEN SELECTED TO MINIMIZE CONTAMINATION.
- MASS OF AIR CLEANING SUBSYSTEM:

HARDWARE	6.4 KG
EXPENDABLES	3.8 KG
TOTAL	10.2 KG

- ALL LEVEL 1 SPECIFICATIONS ARE MET.

TRW

THERMAL CONTROL SUBSYSTEM

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TRW
SYSTEMS GROUP

The Thermal Control Subsystem (TCS) interfaces with the Spacelab heat sinks on the one hand and all remaining subsystems on the other. It must be designed such that the Spacelab heat rejection capabilities (S/L HX, cabin air, avionics air) individually and in total, are not exceeded.

Several ACPL subsystems and subassemblies require precision temperature control with stability, uniformity and measurement specifications down to $0.010^{\circ}C$. Others require only nominal temperature control consistent with cooling dissipative heat loads.

THERMAL CONTROL SUBSYSTEM

FUNCTION:

- THERMAL INTERFACE BETWEEN ALL SUBSYSTEMS AND S/L HEAT SINKS
- ASSURE S/L HEAT REJECTION CONSTRAINTS ARE NOT VIOLATED
- PRECISE TEMPERATURE CONTROL
  - EXPANSION CHAMBER
  - CFD CHAMBER
  - SDL CHAMBER
  - SATURATOR
- NOMINAL TEMPERATURE CONTROL
  - ELECTRONICS
  - ILLUMINATION SUBASSEMBLIES
  - FLUID SUBSYSTEM
  - PARTICLE GENERATORS

TRW

Precision temperature control requirements on ACPL are in the millidegree range, as shown on the following two pages. These could only be achieved by carefully coordinating the design of the various chambers, control electronics, temperature measurement methods and Thermal Control Subsystem hardware. This integrated design, based on the use of thermoelectric coolers, ethylene glycol-water coolant loops and stability-tested thermistors has been shown to meet all of the Level 1 Specification requirements.

THERMAL CONTROL SUBSYSTEM
PRECISION TEMPERATURE CONTROL

EXPANSION CHAMBER THERMAL CONTROL REQUIREMENTS

- SEV TEMPERATURE

  SETABLE WITHIN ± 0.1 °C IN RANGE 0.5 TO 20 °C

  CONSTANT AND KNOWN TO ± 0.05 °C AFTER 20 MINUTES AT A SETPOINT

  UNIFORM TO ± 0.005 °C STEADY STATE AND FOR 100 SEC ACTIVATION PERIODS

- WALL TEMPERATURE

  UNIFORM TO ± 0.1 °C OVER 90% OF INTERIOR SURFACE

  COOLDOWN OVER RANGES BELOW:

dT/dt (°C/MIN)	0.5	1.2	6
TIME (MIN)	60	30	1
TEMPERATURE RANGE (°C)	20 TO -25	20 TO -15	20 TO 0

  TRACKING PRESCRIBED COOLDOWN CURVE WITHIN ± 0.1°C FOR dT/dt ≤ 3 °C/MIN

  CHANGE COOLDOWN RATE BEFORE TEMPERATURE HAS CHANGED BY 0.5 °C

SATURATOR THERMAL CONTROL REQUIREMENTS

- PLATE TEMPERATURES

  OPERATING RANGE OF 5 °C TO 20 °C

  REFERENCE ZONE KNOWN TO ±0.050 °C

  REFERENCE ZONE UNIFORM AND STABLE TO ± 0.02 °C FOR 1000 SECS

TRW

THERMAL CONTROL SUBSYSTEM
PRECISION TEMPERATURE CONTROL (CONT)

CFD CHAMBER THERMAL CONTROL REQUIREMENTS

- PLATE TEMPERATURES
  - OPERATING RANGE OF 5°C TO 25°C, KNOWN TO ± 0.1 °C
  - DIFFERENTIAL BETWEEN PLATES AT ANY VALUE BETWEEN 0 AND 7 °C
  - TEMPERATURE DIFFERENTIAL IN REFERENCE ZONE STABLE, UNIFORM AND KNOWN TO ± 0.01 °C

SDL CHAMBER THERMAL CONTROL REQUIREMENTS

- PLATE TEMPERATURES
  - OPERATING RANGE OF 5°C TO 20 °C, KNOWN TO ± 0.1 °C
  - DIFFERENTIAL TEMPERATURE OF 0 - 10 °C
  - TEMPERATURE DIFFERENTIAL IN REFERENCE ZONE STABLE, UNIFORM AND KNOWN TO ± 0.01 °C

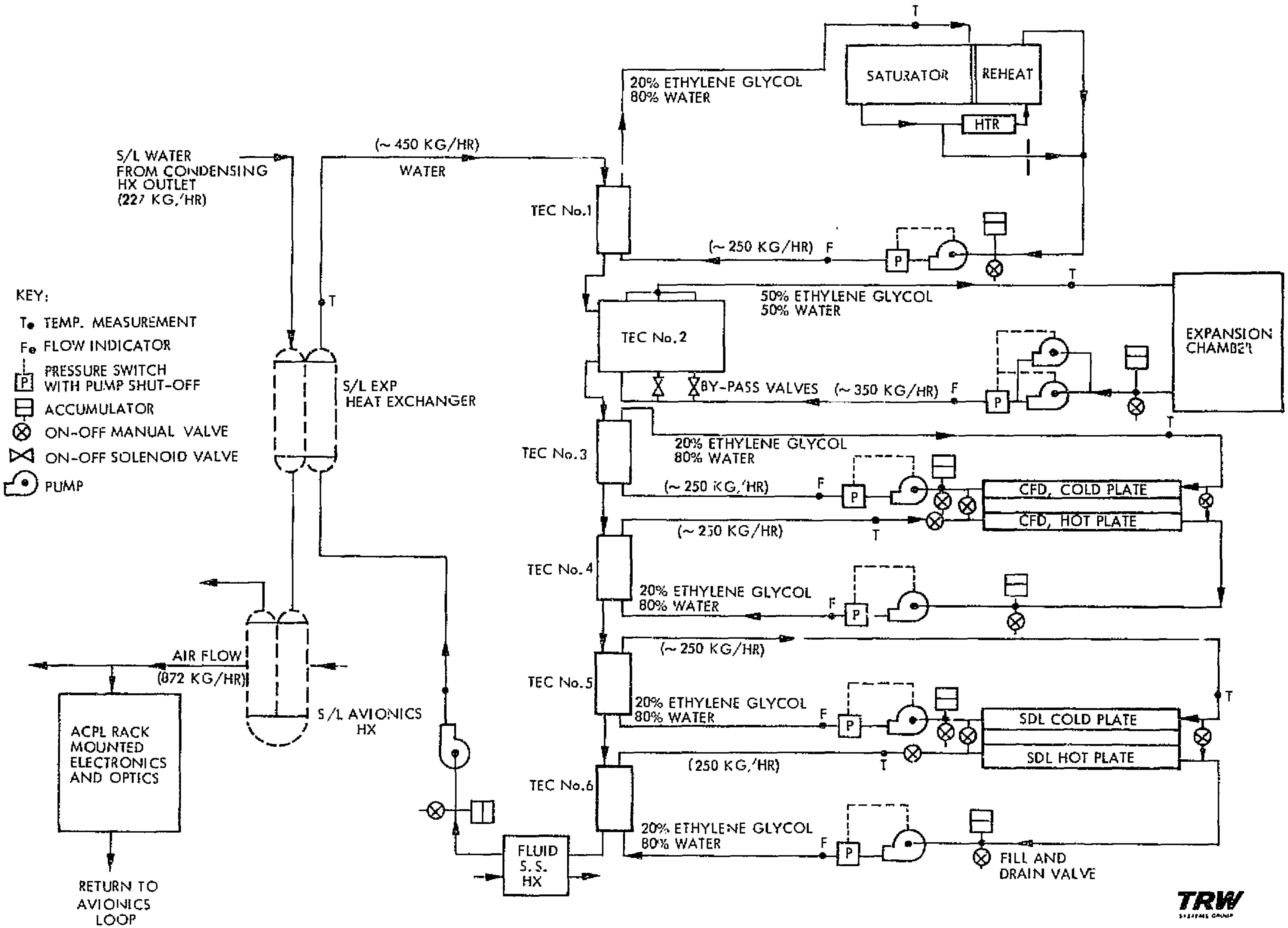
The Thermal Control Subsystem schematic is shown on the facing page.

There are six individually controlled ethylene glycol-water loops for temperature control of the experimental chambers and saturator. Refrigeration for these loops is provided with thermoelectric coolers (TEC's). A water loop removes heat from the hot side of the TEC's for rejection into the Spacelab Experiment Heat Exchanger.

A special feature of the TCS design is the manual valving system provided in the CFD and SDL loops which permits the cold plate loops to supply coolant to both hot and cold plates in parallel. This allows in situ calibration of the ΔT measurement system under zero ΔT conditions when the system is operated under no load conditions.

Most of the electronics heat dissipation is rejected to the avionics air loop. The remainder, as well as other miscellancous heat sources (flashlamps, pumps, etc.) is rejected to the cabin atmosphere. The system has been designed to minimize the heat rejected to the cabin.

ACPL THERMAL CONTROL SUBSYSTEM



Potential coolants for use in the Thermal Control Subsystem were evaluated based on a relative figure of merit. Functional relationships for pressure drop and heat transfer yield a grouping of fluid properties which, if maximized, will maximize the amount of heat transfer per unit pressure drop and temperature drop in a laminar flow system. This grouping or figure of merit is:

$$\frac{K^3 C_p}{\nu}$$

K = Coolant thermal conductivity

C_p = Coolant specific heat

ν = Coolant viscosity

For comparison in the adjoining table, the figure of merit is given relative to a 20% ethylene glycol-water solution at 20°C. Ethylene glycol-water is superior to all others except at -25°C where Freon 21 has a higher figure of merit than the required 50% glycol solution.

THERMAL CONTROL SUBSYSTEM

FLUID PROPERTIES COMPARISON

COOLANT	FREEZING POINT (°C)	VAPOR PRESSURE (ATM) 20°C	VAPOR PRESSURE (ATM) 40°C	SPECIFIC HEAT (20°C) (CAL/G-°C)	THERMAL CONDUCTIVITY 20°C (CAL/CM-SEC-°C)	VISCOSITY (CENTISTOKE) -25°C	VISCOSITY (CENTISTOKE) 0°C	VISCOSITY (CENTISTOKE) 20°C	FIGURE OF MERIT * -25°C	FIGURE OF MERIT * 0°C	FIGURE OF MERIT * 20°C
20% ETHYLENE GLYCOL - H_2O	- 4	0.024	0.063	0.93	12.6×10^{-4}	< F. P.	3.10	1.85	< F. P.	0.59	1.0
50% ETHYLENE GLYCOL - H_2O	- 35	0.017	0.046	0.79	10.0×10^{-4}	30.8	7.3	3.6	0.02	0.10	0.22
F - 113	- 35	0.35	0.71	0.218	1.57×10^{-4}	0.985	.605	0.467	0.001	.002	0.002
COOLANOL 25	< - 35	< 0.1	< 0.1	0.44	3.15×10^{-4}	32.0	12.0	6.0	.0005	.001	0.002
FC - 75	< - 93	0.033	0.079	0.244	3.3×10^{-4}	2.5	1.02	0.86	0.003	.008	0.01
DC - 331	- 100	< 0.1	< 0.1	0.423	3.22×10^{-4}	35.0	17.0	12.0	.0004	.0009	0.001
F - 21	- 135	1.5	2.9	0.256	2.60×10^{-4}	0.380	.296	0.256	0.03	0.02	0.02

* FIGURE OF MERIT, $K^3 Cp/\mu$, IS RELATIVE TO 20% GLYCOL - H_2O AT 20°C.

TRW SYSTEMS GROUP

The coolant loops will be operated at sub-atmospheric pressure using ethylene glycol-water solutions. A pressure cut-off switch is included to preclude the possibility of positive expulsion of coolant by the pump should a leak occur. The leakage rate of ethylene glycol by diffusion is calculated to be more than two orders of magnitude less than the allowable value.

Use of a high vapor pressure coolant such as F-21 would require a sealed pressure chamber for each loop as a safety backup. This incurs unacceptable costs, weight and complexity against a small advantage in coolant performance at the lower temperature levels.

THERMAL CONTROL SUBSYSTEM
COOLANT SAFETY CONSIDERATIONS

COOLANTS WITH VAPOR PRESSURES > P AMB

- EXAMPLE (FREON-21, $P_{SAT\ 20^\circ C}$ = 1.5 ATM)
- HAS HIGH FIGURE OF MERIT ONLY AT MINIMUM TEMPERATURE LEVEL
- WOULD REQUIRE SEALED PRESSURE CHAMBER AROUND EACH SYSTEM AS SAFETY BACK-UP
- HIGH COST IN WEIGHT, COMPLEXITY AND DOLLARS

COOLANTS WITH VAPOR PRESSURES < P_{AMB}

- EXAMPLES (E.G. - H_2O, FC-75, COOLANOL 25)
- E.G. - H_2O HAS HIGHEST FIGURE OF MERIT
- USE 50% SOLUTION FOR EXPANSION CHAMBER TO PREVENT FREEZING, 20% IN OTHER LOOPS
- PROVIDE PRESSURE SWITCH TO TURN OFF PUMP AS A SAFETY BACK-UP IF LEAK OCCURS
- MAXIMUM CALCULATED DIFFUSION LEAK RATE FOR 2 CM^2 OPENING = 12 MG/HR COMPARED WITH 3420 MG/HR ALLOWABLE

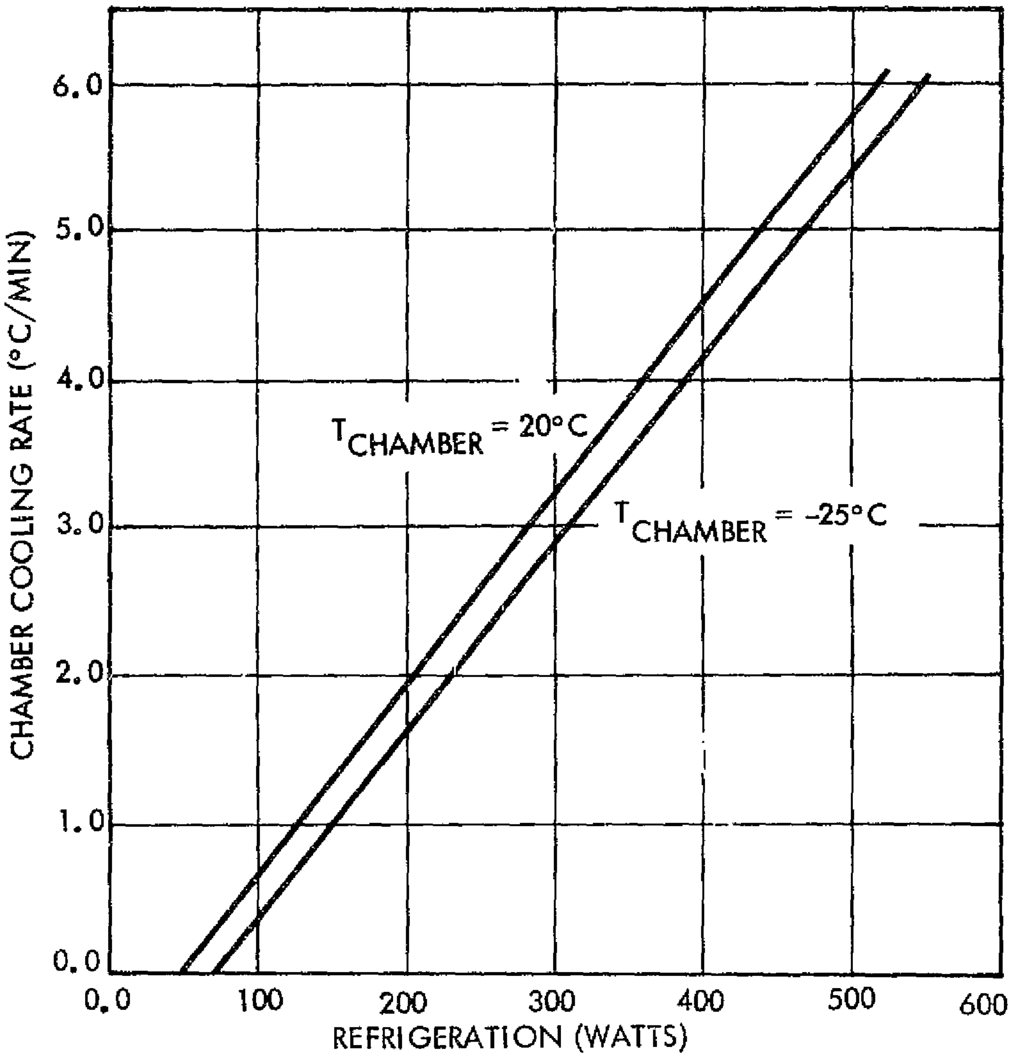
- ETHYLENE-GLYCOL/WATER SELECTED FOR SUPERIOR THERMAL PERFORMANCE PLUS SAFETY OF SUB-ATMOSPHERIC OPERATION

TRW

The Expansion Chamber requires a high rate of refrigeration to obtain the cool-down rates of up to 6°C per minute required. The double wall concept as described in the Expansion Chamber section was configured to minimize the amount of refrigeration required and simultaneously meet the temperature uniformity requirements. The refrigeration values shown include not only that required for the chamber, but also what is required to cool the plumbing, pump, coolant inventory and cold side TEC heat exchanger.

THERMAL CONTROL SUBSYSTEM

EXPANSION CHAMBER REFRIGERATION REQUIRED



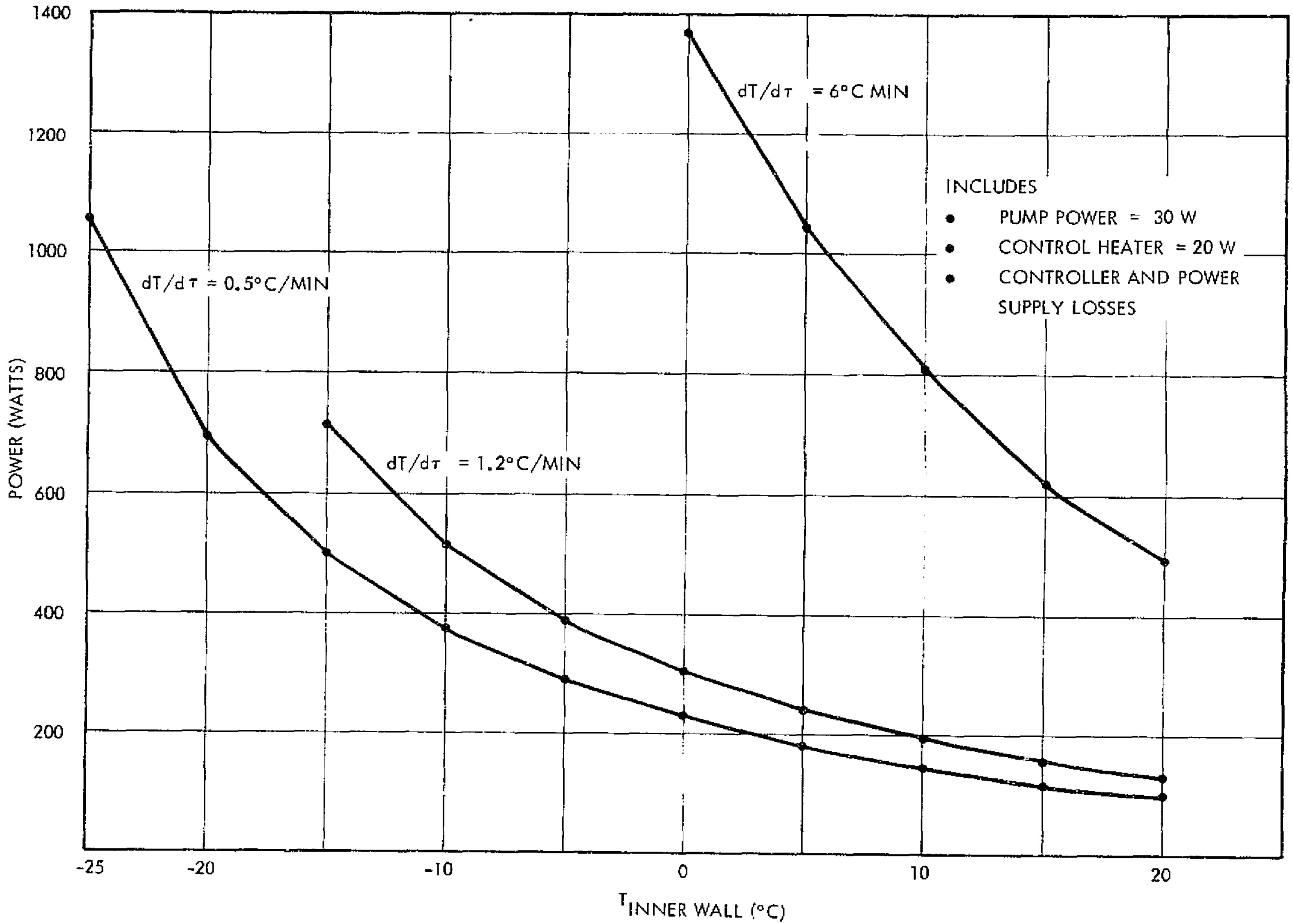
- DOUBLE WALL CONCEPT
  T_{INNER} = 0.051 CM
  T_{OUTER} = 0.115 CM
- PUMP INPUT = 30 WATTS
- 5.08 CM FOAM INSULATION
- 20°C AMBIENT
- 20 WATT CONTROL HEATER

TRW

The curves on the facing page show the electrical power required to chill the Expansion Chamber at various cooling rates as a function of the chamber temperature. Clearly, lowering the wall temperature degrades the thermo-electric cooler performance (for a given sink temperature) and increases the electrical power required to maintain a given cooling rate. The electrical power requirements shown include that needed to drive the coolers, power supplies, controllers, pump and inner wall heaters. Note that power requirements above 1 Kw exist only for narrow regions of the operating envelope and would occur only as short term peaks. The 6°C/minute cooling rate which requires the highest input power need only be maintained for 1 minute continuously.

THERMAL CONTROL SUBSYSTEM

EXPANSION CHAMBER ELECTRICAL POWER REQUIREMENT USING THERMOELECTRIC COOLERS



Thermoelectric coolers have been chosen over evaporative coolers for use as the expansion chamber refrigeration source. During Concept Review these were the only two viable refrigeration sources identified. The choice of thermoelectrics was made because of the lower cost associated with their implementation and the fact that electrical power requirements are at acceptable levels with the present chamber and TEC designs.

THERMAL CONTROL SUBSYSTEM
THERMOELECTRIC COOLERS VS EVAPORATIVE COOLERS

THERMOELECTRIC COOLER	EVAPORATIVE COOLER
• ACCEPTABLE ELECTRICAL POWER INPUT	• SAVINGS IN USAGE OF S/L ELECTRICAL POWER
• SLIGHT MODIFICATION OF COMMERCIALLY AVAILABLE UNITS	• DEVELOPMENT ITEM WHICH IS NOT CONSISTENT WITH LOW COST APPROACH
• MODULAR APPROACH GIVES OPTIMUM EFFICIENCY FOR EXPANSION CHAMBER AND COMMONALITY WITH OTHER LOOPS	• INTERFACE WITH EXPERIMENT VENT COMPLICATES INTEGRATION AND TESTING
• ALSO GIVES COMMONALITY FOR CONTROL AND DATA HARDWARE	• ACCEPTABLE FLUIDS FOR BELOW 0°C OPERATION HAVE LOW HEATS OF VAPORIZATION. REQUIRE LARGE EXPENDABLE INVENTORY.
• CLEAR CHOICE FOR MINIMUM COST APPROACH	

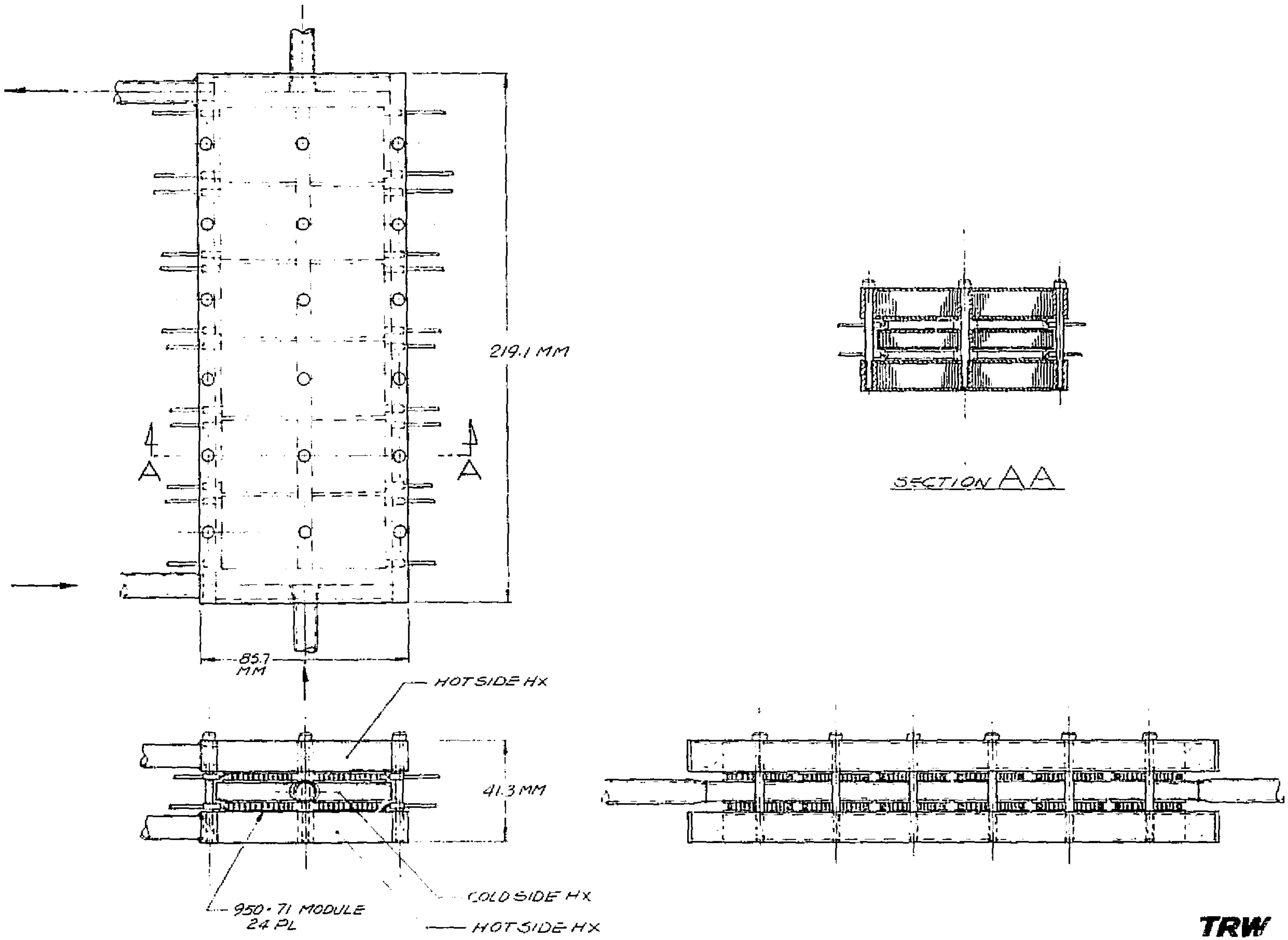
• SELECTED THERMOELECTRIC COOLERS FOR INITIAL ACPL

TRW

The basic thermoelectric cooler (TEC) module design is shown on the facing page. This same module is used in all coolant loops. Three units are used in the Expansion Chamber and one in each of the other loops. The design utilizes a central cold side heat exchanger with thermoelectric modules on each side. This assembly is then clamped in compression between two hot side heat exchangers. Hot to cold side conduction via mounting supports is minimized in this manner. All heat exchangers are finned structures to minimize weight (most important for the cold side HX where rapid slewing capability is required) and to yield high heat transfer effectiveness.

THERMAL CONTROL SUBSYSTEM

PRELIMINARY DESIGN LAYOUT : TEM MODULE

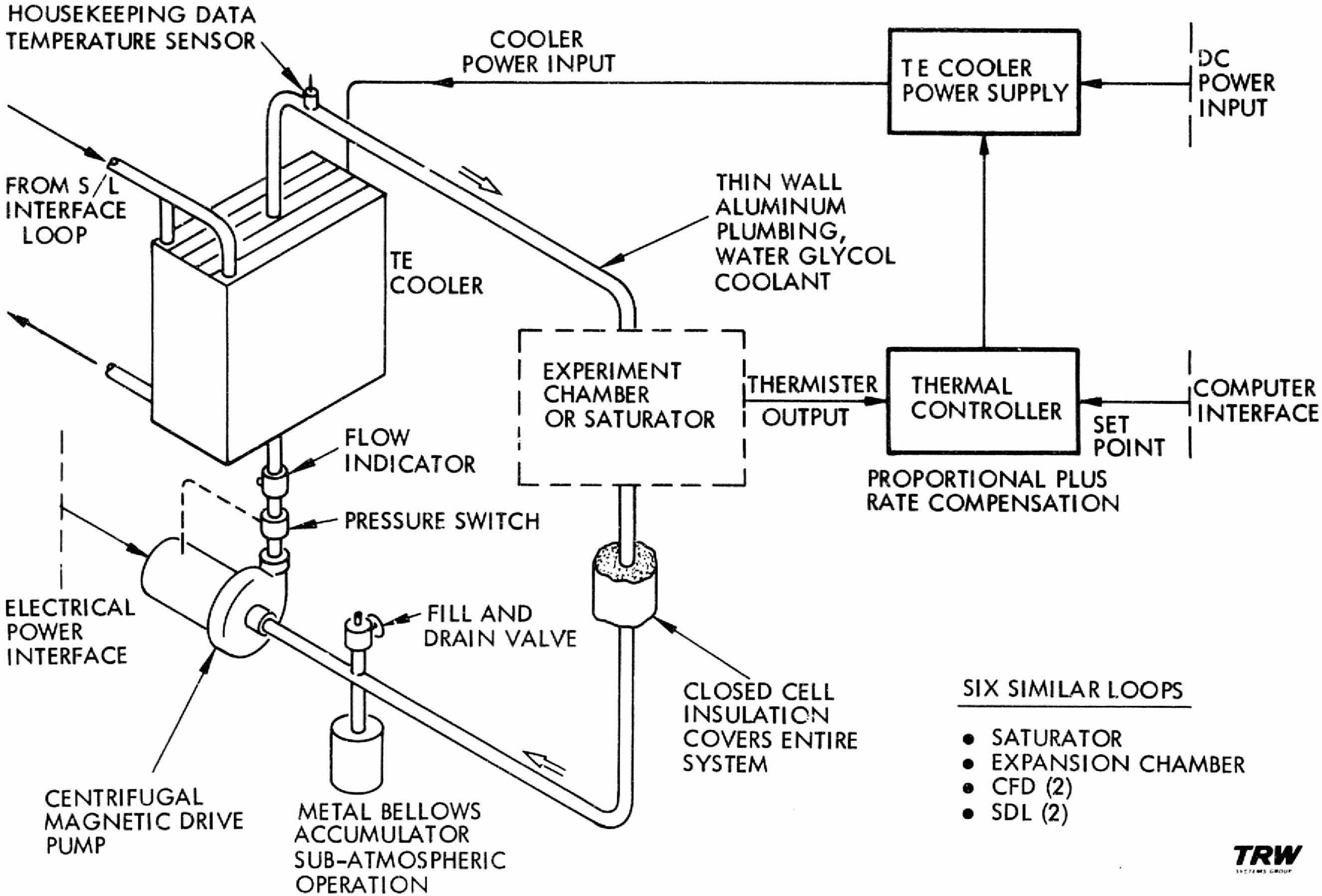


TRW
SYSTEMS GROUP

There are seven coolant loops in the ACPL Thermal Control Subsystem (Expansion Chamber, Saturator, CFD(2), SDL(2) and the experiment heat exchanger interface loop, which cools the thermoelectric cooler hot sides). A great amount of hardware commonality exists among the loops which leads to a low cost system. Items such as accumulators, fill and drain valves, pressure switches, flow indicators, insulation and temperature sensors are identical. There are two types of pump/motor combinations; one high capacity design for the Expansion Chamber and experiment heat exchanger loops and a smaller capacity design for the remaining applications. As discussed previously, the thermoelectric coolers all use a common module.

THERMAL CONTROL SUBSYSTEM

COOLANT LOOP DESIGN FEATURES



SIX SIMILAR LOOPS

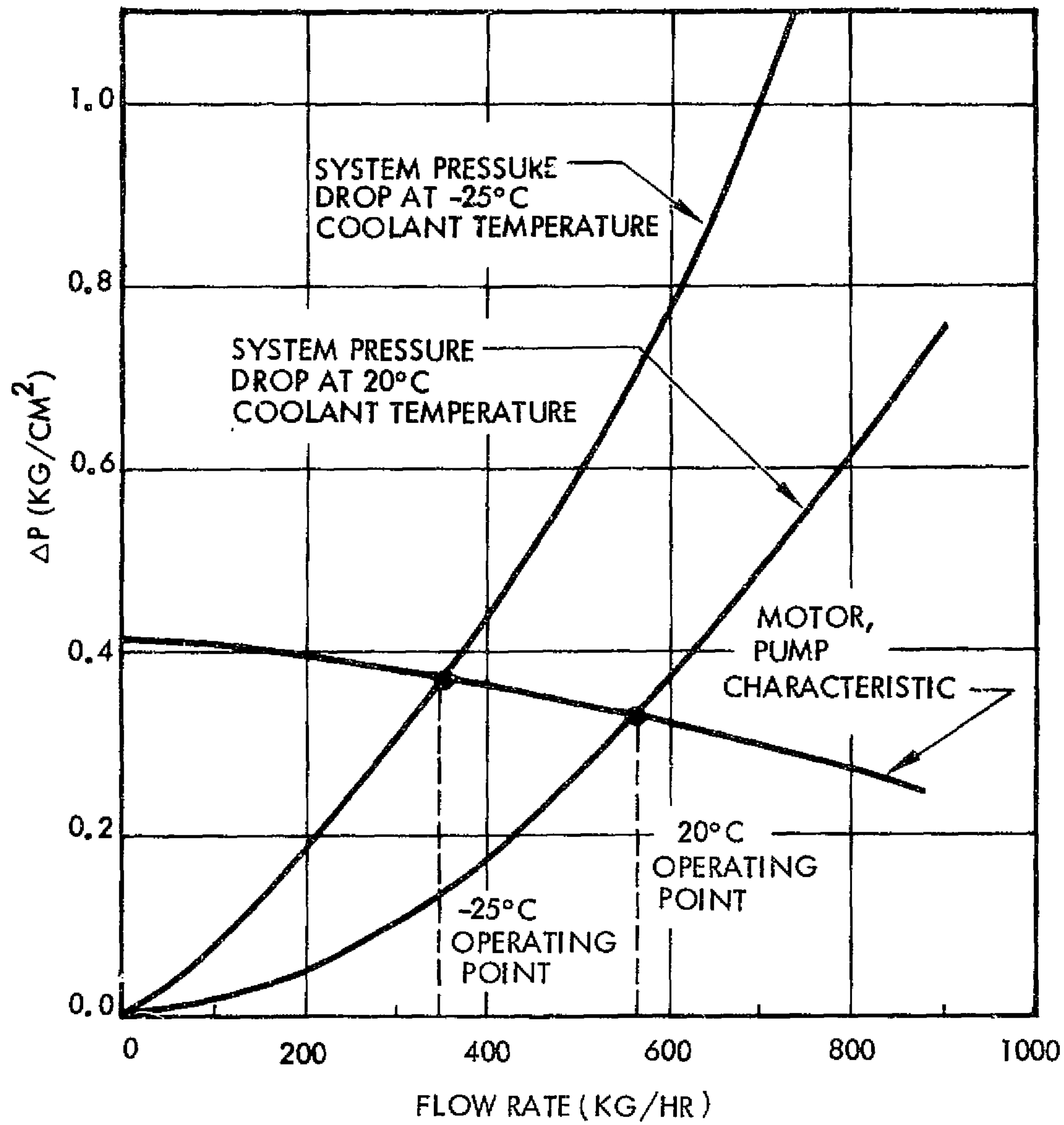
- SATURATOR
- EXPANSION CHAMBER
- CFD (2)
- SDL (2)

TRW

The viscosity of ethylene glycol-water solutions varies considerably with temperature. Consequently, the flow rate in a given loop will vary with temperature such that the pressure drop matches the motor-pump characteristic. The curves shown on the facing page apply to the Expansion Chamber loop which employs a 50% ethylene glycol-50% water solution as the coolant.

THERMAL CONTROL SUBSYSTEM

COOLANT LOOP PRESSURE DROP AND FLOW RATE



EXPANSION CHAMBE[illegible] LOOP

COOLANT = 50% ETHYLENE GLYCOL
50% WATER

PUMP/MOTOR DATA

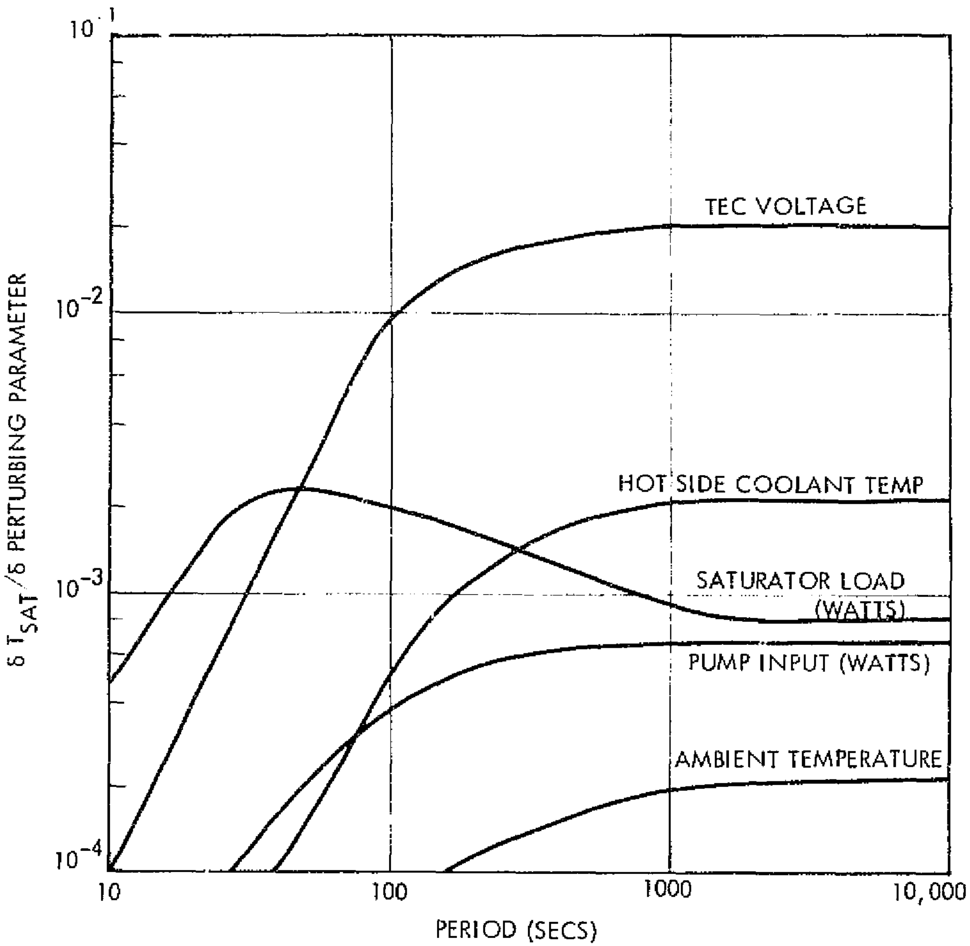
- CENTRIFUGAL TYPE
- INPUT POWER, 24 VOLTS
  - -25°C = 32 WATTS
  - 20°C = 34 WATTS

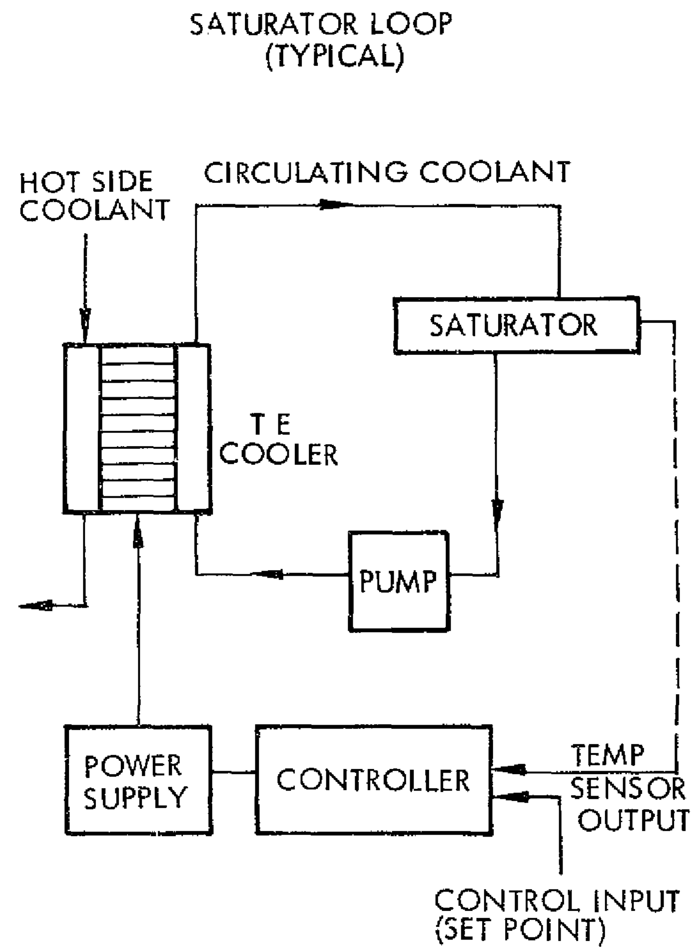
TRW

Typical of the loop stability analyses performed is a small signal analysis on the Saturator loop and control system to evaluate the effect of internal and external perturbations on the reference zone temperature. The ratio of reference zone temperature variation to the change in a given perturbing parameter is given as a function of perturbation period. Steady state or step changes are given for this system at periods greater than about 1000 seconds. This data is related to allowable changes in these parameters on the following pages.

THERMAL CONTROL SUBSYSTEM

TEMPERATURE STABILITY ANALYSIS





CONTROL SYSTEM SCHEMATIC

TRW

Anticipated temperature stability of the Saturator is tabulated on the facing page and based on the small signal analysis results. Adding all the maximum anticipated effects on the Saturator temperature absolutely gives a total of $\pm 0.012^{\circ}C$. A more realistic RSS value for the Saturator temperature stability is $\pm 0.007^{\circ}C$.

Similar stability levels are anticipated for the CFD and SDL thermal control loops at steady state conditions.

THERMAL CONTROL SUBSYSTEM

SATURATOR TEMPERATURE STABILITY ANALYSIS SUMMARY

PERTURBING PARAMETER	MAXIMUM INFLUENCE ON SATURATOR TEMP	1000 SECOND ALLOWABLE VARIATION FOR ± .02 °C δT	ANTICIPATED MAXIMUM VARIATION	SATURATOR δT (°C)
TEC VOLTAGE	.02 °C/VOLT	± 1.0 VOLT	± 0.25 VOLT	± .005
SATURATOR LOAD	.0025 °C/WATT	± 8.0 WATTS	± 1.25 WATTS	± .003
HOT SIDE COOLANT TEMP.	.0021 °C/°C	± 9.5 °C	± 1.9 °C	± .004
PUMP INPUT	.00063 °C/WATT	± 31.7 WATTS	± 0.03 WATT	.000
AMBIENT TEMP	.00022 °C/°C	± 89.4 °C	± 1.0 °C	.000

ABSOLUTE TOTAL $\delta T_{SAT} = \pm 0.012$ °C

RSS TOTAL $\delta T_{SAT} = \pm 0.007$ °C

- SATURATOR LOOP TEMPERATURE STABILITY $\approx$ ± 0.007 °C
- SIMILAR PERFORMANCE FOR CFD AND SDL LOOPS
- SATURATOR, CFD AND SDL LOOPS ALL MEET LEVEL I SPECIFICATION STABILITY REQUIREMENTS

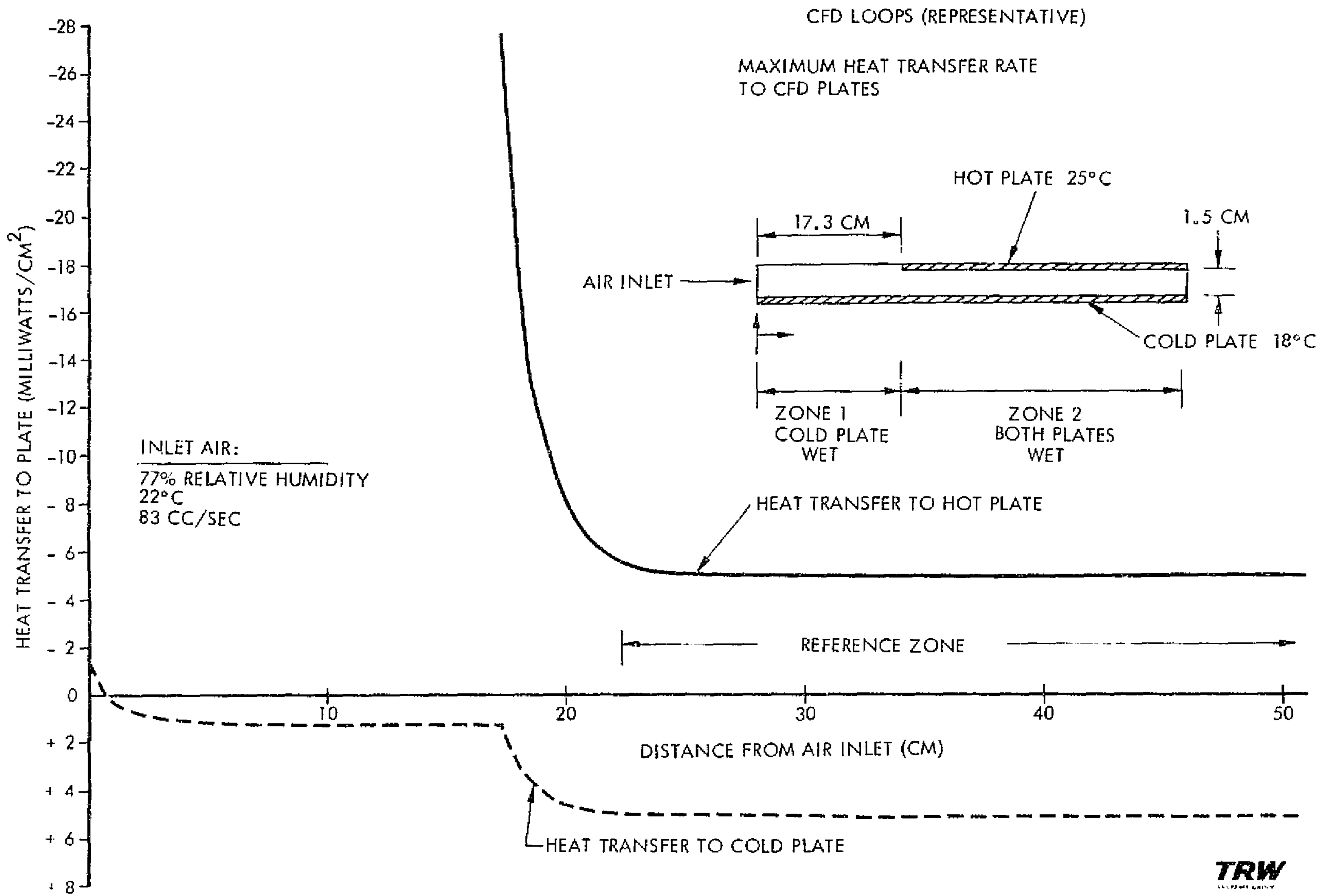
TRW SYSTEMS GROUP

In addition to temperature stability, the coordinated design of the TCS loops and the experimental chambers must assure that temperature uniformity requirements are met. It was shown at Interim Review that the Saturator plate temperature uniformity requirements were substantially exceeded. However, a more difficult requirement is posed by the CFD since there exist significant thermal loads in the reference zone.

Worst case heat loads for the CFD are shown on the facing page. The loads shown include condensation and evaporation as well as conduction heat transfer between plates.

THERMAL CONTROL SUBSYSTEM

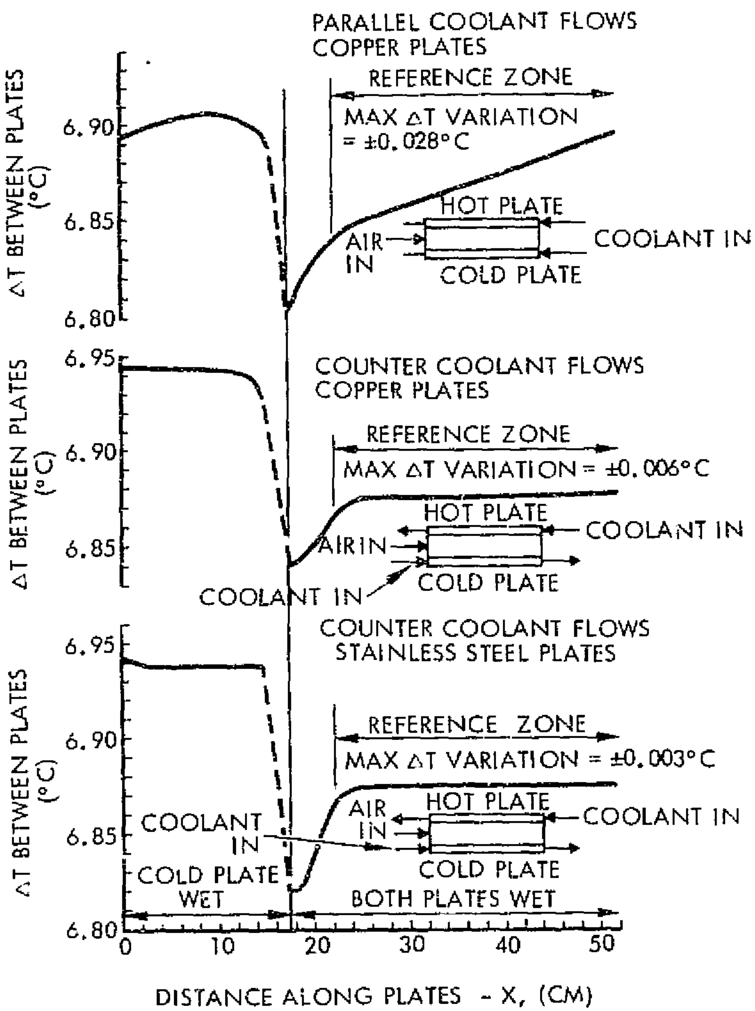
TEMPERATURE UNIFORMITY ANALYSIS



An analysis model of the CFD plates was constructed and used to determine plate temperature distributions for a variety of conditions. As shown in the upper figure, parallel flow in the plates is unacceptable from the standpoint of ΔT variation in the reference zone. However, counterflowing the hot and cold plate coolants results in a very constant ΔT in the reference zone. Results also show that stainless steel plates are somewhat better than copper plates in isolating the disturbance at the point where the hot plate first becomes wet. For this reason, as well as relative ease of fabrication, stainless steel plates have been selected for the preliminary CFD design.

THERMAL CONTROL SUBSYSTEM

CFD PLATE TEMPERATURE DIFFERENCE TRADE STUDIES



- AIR FLOW RATE = 83 CM^3/SEC AT 22°C AND 77% R. H.
- COOLANT FLOW (20% E. G.- WATER) = 227 KG/HR PER PLATE
- COOLANT INLET TEMPERATURES:
  HOT PLATE: 25.0°C
  COLD PLATE: 18.0°C

RESULTS OF NUMERICAL MODELLING

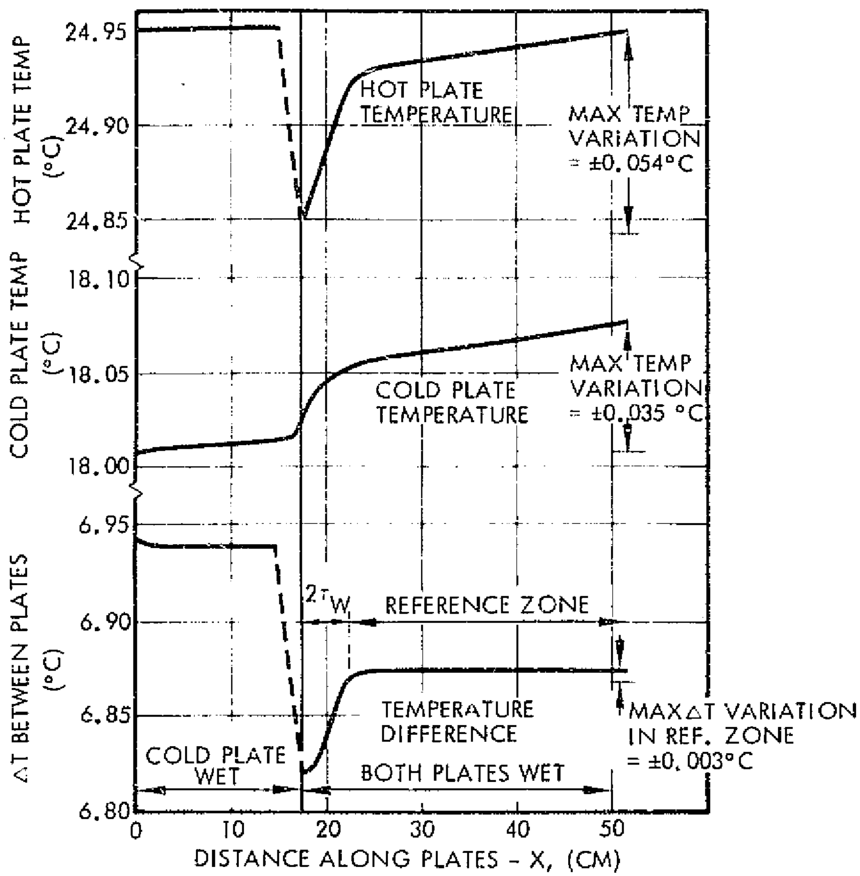
- COUNTER COOLANT FLOWS YIELD MORE UNIFORM ΔT IN REFERENCE ZONE THAN PARALLEL COOLANT FLOWS
- STAINLESS STEEL PLATES YIELD MORE UNIFORM ΔT IN REFERENCE ZONE THAN COPPER PLATES

TRW

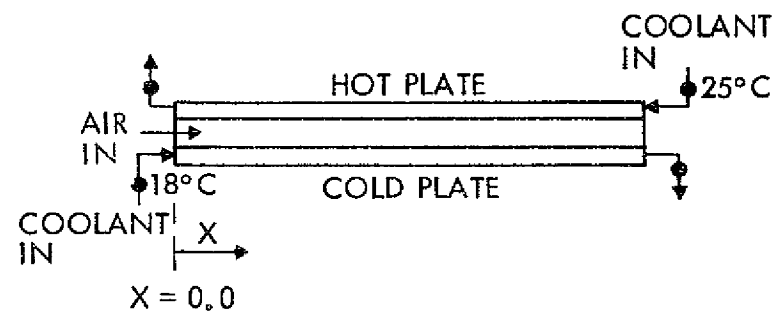
Hot and cold plate temperature distributions for the chosen stainless steel design are shown. The plates have a temperature uniformity of $\pm 0.054^{\circ}C$ and $\pm 0.035^{\circ}C$ while through the use of counterflow the temperature difference in the reference zone is constant to $\pm 0.003^{\circ}C$. The high coolant flow rate relative to the small heat load gives a coolant temperature rise or drop of only approximately $0.030^{\circ}C$. This results in the design being insensitive to small variations in flow which might occur due to manufacturing imperfections.

THERMAL CONTROL SUBSYSTEM

CFD PLATE TEMPERATURE DISTRIBUTIONS



- STAINLESS STEEL PLATES
- AIR FLOW RATE = 83 CM^3/SEC AT 22°C AND 77% R.H.
- COOLANT FLOW (20% E.G.-WATER) = 227 KG/HR PER PLATE

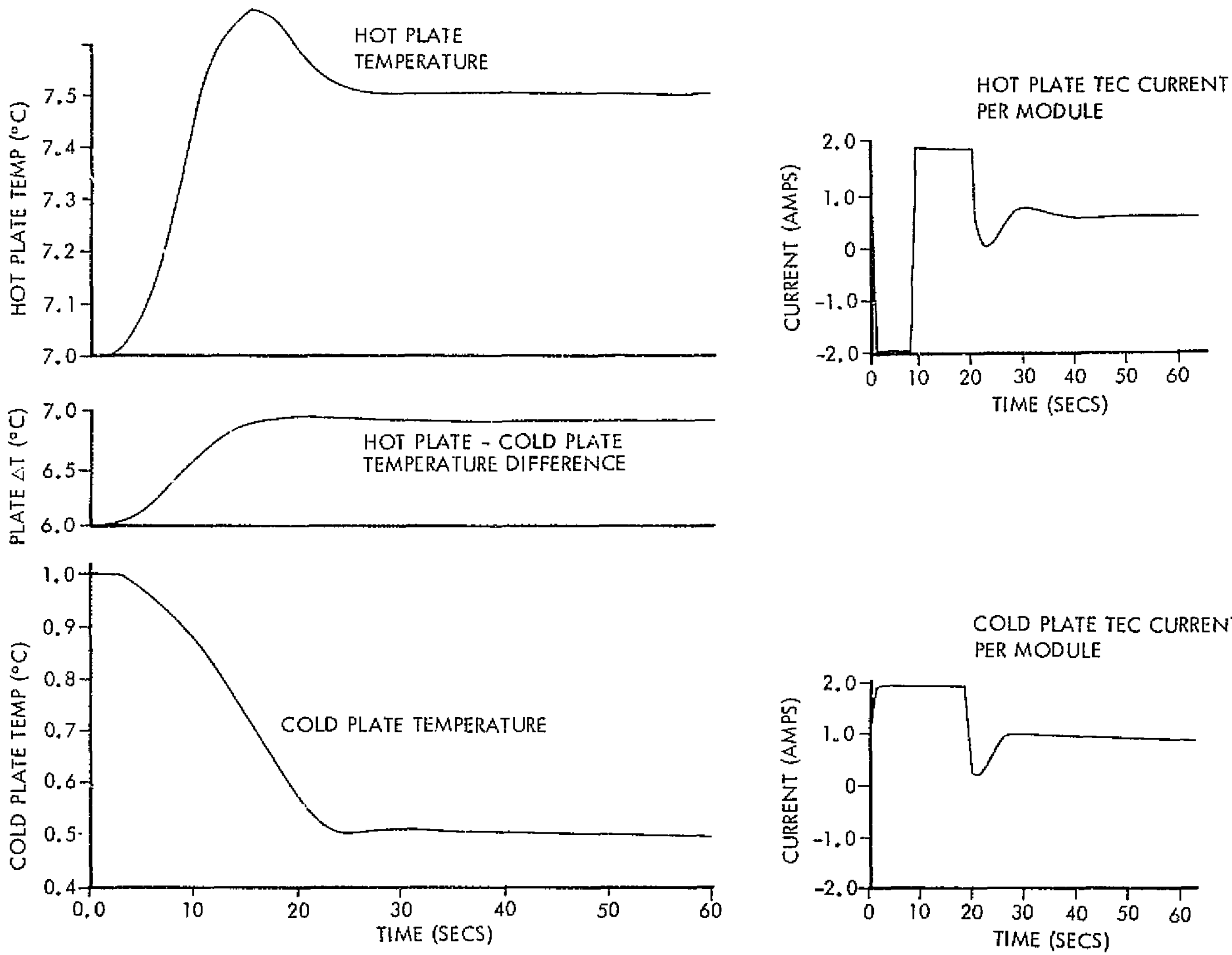


- DESIGN MEETS LEVEL 1 SPECIFICATION FOR PLATE TEMPERATURE AND ΔT UNIFORMITY (±0.1 °C AND ±0.01 °C, RESPECTIVELY)

TRW

As well as maintaining steady state temperature control, the thermal control loops must provide rapid heating and cooling capabilities to adjust temperatures. For example, once the initial temperature conditions are established, the CFD will be operated by increments in ΔT achieved by stepping both the hot and cold plates in increments of $\approx 0.5^{\circ}C$. The thermoelectric coolers, one heating and the other cooling, will be used to change the plate temperatures. Thermal modeling results show that only 30 seconds are required to step the plates $0.5^{\circ}C$ and stabilize at the new temperature; a necessary condition for rapid CFD aerosol characterizations. The thermoelectric cooler controllers have a current limit of 2 amps per module and operate with proportional control plus rate compensation to achieve rapid stabilization at the new temperature levels.

THERMAL CONTROL SUBSYSTEM
TEMPERATURE RAMP ANALYSIS (CFD)



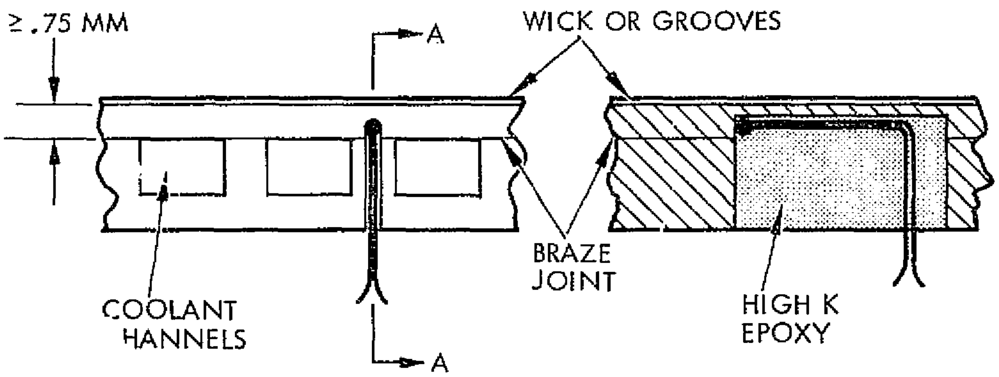
- WORST CASE CONDITIONS
- 1°C INCREMENT IN ΔT ESTABLISHED IN < 30 SEC

TRW

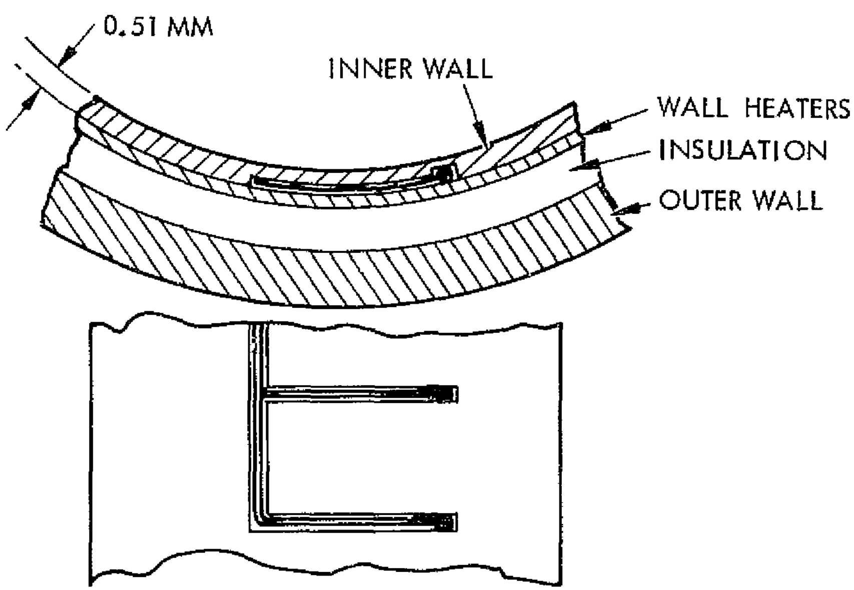
The figures on the facing page show typical thermistor bead installations for the various precision temperature-controlled chambers. These installations are designed to minimize temperature measurement errors.

THERMAL CONTROL SUBSYSTEM

TEMPERATURE MEASUREMENT WITH THERMISTORS



TYPICAL INSTALLATION FOR SATURATOR, CFD AND SDL



TYPICAL INSTALLATION FOR EXPANSION CHAMBER

- THERMISTOR BEAD LOCATED AS CLOSE TO CRITICAL SURFACE POSSIBLE
- LEADS ROUTED >50 WIRE DIAMETERS IN RELATIVELY ISOTHERMAL ZONE TO MINIMIZE CONDUCTION ERRORS
- SENSOR GROOVE FILLED WITH THERMALLY CONDUCTING EPOXY
- MINIMUM BEAD DIAMETER = 0.36 MM FOR LONG TERM STABILITY. REQUIRES WALL THICKNESS ≥ 0.50 MM FOR INSTALLATION IN REGION OF MINIMAL THERMAL GRADIENT

TRW

The facing table shows our estimates for the accuracy with which temperatures can be measured in the ACPL. We beleive that absolute temperatures can be measured within requirements using calibrated thermistors. However, temperature differences can only be measured with the required 0.010^{o}C accuracy by performing an in situ calibration of the measurement system at zero ΔT. This will eliminate drift and calibration errors and minimize installation errors.

THERMAL CONTROL SUBSYSTEM
TEMPERATURE MEASUREMENT ACCURACY

ERROR SOURCE	ERROR CONTRIBUTION			
	STEADY STATE T (CFD, SDL, EXP. CH., SAT)	STEADY STATE ΔT (CFD, SDL) COMPONENT CALIB.	STEADY STATE ΔT (CFD, SDL) IN SITU CALIB.	DYNAMIC T (-6°C/MIN) (EXP. CH.)
ELECTRONICS	± 0.005 °C	± 0.002 °C	± 0.001 °C	± 0.005 °C
SENSOR SELF HEATING (UNCERT)	± 0.002	± 0.003	0	± 0.002
SENSOR MOUNTING	± 0.040	± 0.057	± 0.007	± 0.044
SENSOR CALIBRATION	± 0.005	± 0.0015	0	± 0.005
SENSOR DRIFT (1 YR)	± 0.005	± 0.007	0	± 0.005
RSS TOTALS	± 0.041	± 0.057	± 0.007	± 0.045
SENSOR DRIFT + RSS OF REMAINDER	± 0.046	± 0.064	± 0.007	± 0.050
REQUIRED ACCURACY	± 0.050	± 0.010	± 0.010	± 0.100

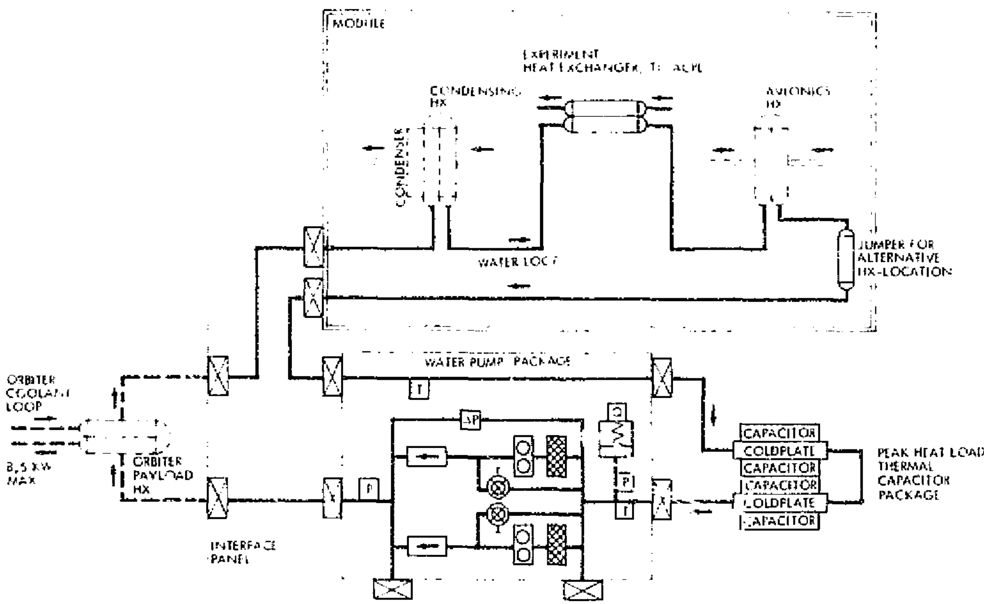
- UNCERTAINTY IN T MEASUREMENTS WITHIN REQUIREMENTS
- UNCERTAINTY IN ΔT MEASUREMENTS WITHIN REQUIREMENTS USING PROVISION FOR IN SITU CALIBRATION AT ZERO ΔT

TRW SYSTEMS GROUP

ACPL heat dissipation is transferred to the Spacelab heat rejection system via Experiment Heat Exchanger, the Avionics Air Heat Exchanger and the Condensing Heat Exchanger (cabin air). The Spacelab heat rejection system has constraints on the amount of heat which can be rejected, as listed. This heat rejection budget must be allocated among all experiments on a particular flight and the ACPL is designed to use only a small portion of the total capability.

THERMAL CONTROL SUBSYSTEM

SPACELAB HEATREJECTION CAPABILITIES



SPACELAB TCS SCHEMATIC

- AVERAGE LOAD CAPABILITY
  - CABIN AIR, 1 KW
  - AVIONICS AIR, 3 KW
  - EXPER. HX, 4 KW
  - ALL THREE COMBINED, 4 KW
- PEAK LOAD TO 8 KW FOR 15 MIN EVERY 3 HOURS IF PALLET FREON LOOP NOT INSTALLED
- USE OF MISSION DEPENDENT EQUIPMENT (E.G. S/L EXPER. COMPUTER AND CRT) REDUCES CAPABILITY AVAILABLE FOR EXPERIMENTAL EQUIPMENT TO 3.4 KW AVERAGE.
- NOMINAL INLET TEMP. TO EXPER. HX = 17.8 °C ASSUMING 1 KW EXPERIMENT HEAT REJECTION TO CABIN LOOP

TRW

Heat rejection by ACPL components is tabulated for standby where chambers are all at ambient temperature and for worst case operation of each of the chambers. Requirements are far below the capabilities of the Spacelab system and individual components. In general, the maximum heat rejection is greater than the corresponding electrical power input because heat is being removed from the chambers to lower their temperature. It is important to note that the rather high total peak rates shown are of very short duration and will be absorbed by the Spacelab TCS thermal mass with insignificant temperature rise.

THERMAL CONTROL SUBSYSTEM

ACPL HEAT REJECTION REQUIREMENTS

MODE	HEAT REJECTION (W)			
	EXPER. HX	AVIONICS HX	CABIN HX	TOTAL
ACPL STAND-BY	90	320	310	720
EXPANSION CHAMBER OPERATION PEAK	1735	665	360	2760
CFD OPERATION PEAK	835	390	320	1545
SDL OPERATION PEAK	835	420	325	1580

- PEAK ACPL REQUIREMENTS $<$ SPACELAB CAPABILITIES
- PEAK ACPL THERMAL LOADS OF VERY SHORT DURATION (≤ 6 MINUTES) AND ARE ABSORBED BY SPACELAB TCS THERMAL MASS

TRW

CONTROL AND DATA SUBSYSTEM

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TRW

The configuration of the Control and Data Subsystem is the result of an interactive systems design approach which traded off design parameters (cost, accuracy, power, etc.) with interfacing subsystems to achieve a realistic cost effective system. Spacelab CDMS facilities were used wherever cost effective and did not affect scientific objections. The CAMAC standard was selected to allow for flexibility and growth and to utilize the extensive range of commercial CAMAC equipment.

CONTROL AND DATA SUBSYSTEM

GENERAL CONSIDERATIONS

- APPROACH DESIGN FROM A TOTAL SYSTEMS VIEWPOINT
- MAKE COST EFFECTIVE USE OF SPACELAB CDMS FACILITIES
- USE COMMERCIAL EQUIPMENT WHERE FEASIBLE
- ADOPT A BUS STRUCTURED MODULAR STANDARD TO ALLOW FOR GROWTH AND FLEXIBILITY

SPECIFIC CONSIDERATIONS

- ACPL INTERFACE WITH SPACELAB CDMS IS RAU OUTPUT
- USE CAMAC (IEEE 583) STANDARD
- CLOSE CONTROL LOOPS LOCALLY
- PROVIDE AN OPERATORS PANEL AT THE ACPL CONSOLE

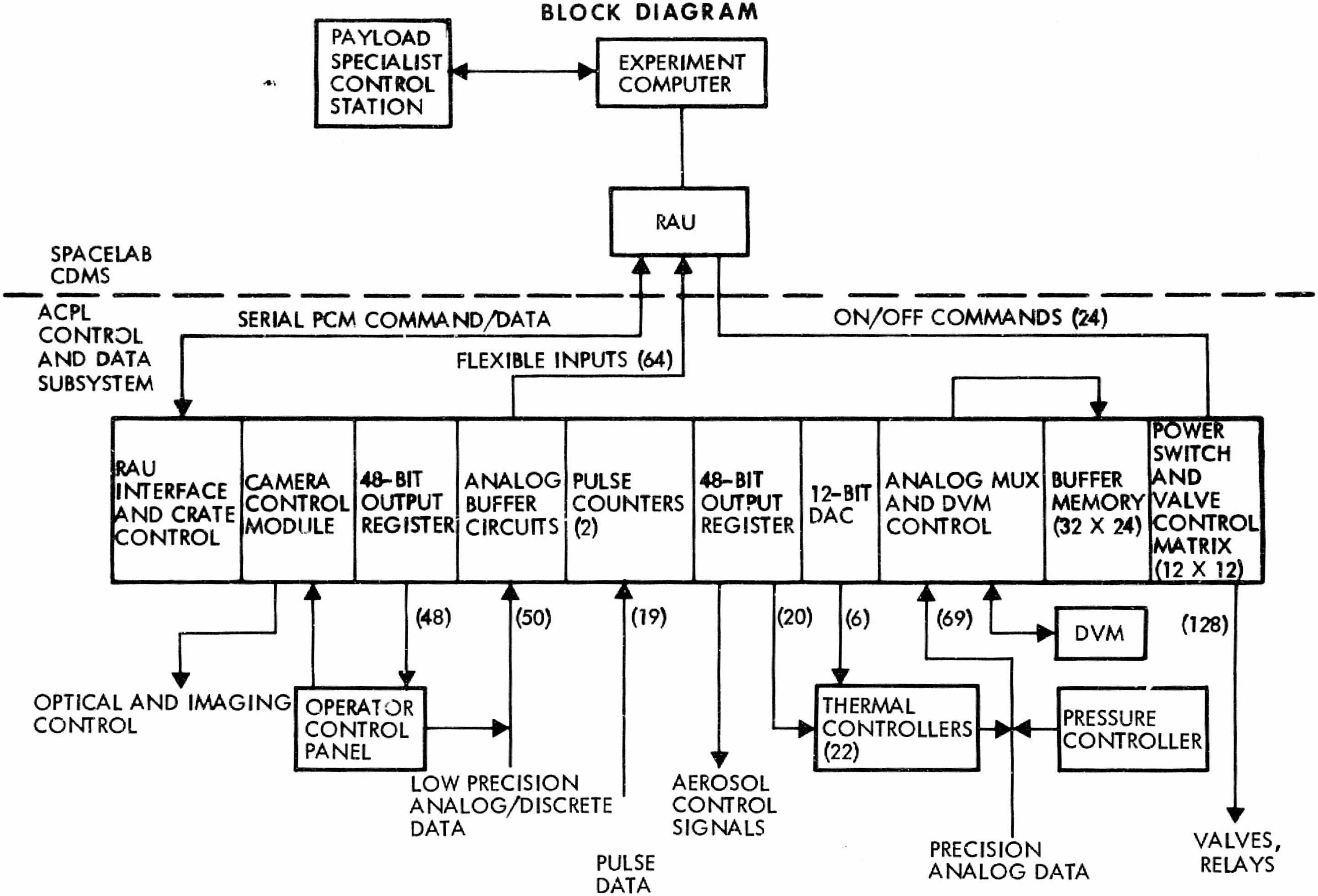
TRW

The block diagram shows the major functional blocks of the Control and Data Subsystem.

The majority of Control and Data Subsystem is composed of commercial and special build CAMAC equipment mounted in a single CAMAC crate. The interface with the Spacelab CDMS is through a single RAU. Power switching and solenoid valve operation is performed under the control of RAU discrete commands. All other computer commanded functions (set point adjustment, camera control, precision data monitoring, etc.) are performed through the serial PCM command/data link.

CONTROL AND DATA SUBSYSTEM

BLOCK DIAGRAM



TRW SYSTEMS GROUP

The ACPL Control and Data Subsystem requires approximately one half the facilities of an experimental RAU. Thus, although provisions for power and mounting have been provided within ACPL, a dedicated RAU is not required. The interface between the Spacelab CDMS and the ACPL is the RAU to-experiment output.

CONTROL AND DATA SUBSYSTEM

ACPL USAGE OF RAU FUNCTIONS

- OPTIMUM USAGE OF RAU TO MINIMIZE ACPL HARDWARE COSTS
- ACPL REQUIRES APPROXIMATELY 1/2 CAPABILITY OF AN RAU
- RAU 8-BIT A/D CONVERTER RESOLUTION NOT SUFFICIENT FOR PRECISION MEASUREMENTS
- INTERFACE SERIAL PCM COMMAND/DATA CHANNEL TO CAMAC DATAWAY

RAU CAPABILITIES	ACPL USAGE
1 USER TIME CLOCK	1 USER TIME CLOCK
1 USER TIME CLOCK UPDATE	–
4 SERIAL PCM COMMAND CHANNELS	1 SERIAL PCM COMMAND CHANNEL
4 SERIAL PCM DATA CHANNELS	1 SERIAL PCM DATA CHANNEL
128 FLEXIBLE INPUTS	64 FLEXIBLE INPUTS
64 ON/OFF COMMANDS	24 ON/OFF COMMANDS

TRW SYSTEMS GROUP

Data flow is controlled by the computer either through the RAU flexible inputs or through the serial PCM data/command channel via the CAMAC dataway. Discrete measurements are required by the flow indicator and the Operator Panel data select switches. Pulse data is derived from the flow meters and the OPC PHA. Analog data is sampled by either the RAU flexible inputs or the precision analog data system.

CONTROL AND DATA SUBSYSTEM

ACPL DATA

- ACPL REQUIRES THE MEASUREMENT OF 138 PARAMETERS

  25 DISCRETE MEASUREMENTS

  19 PULSE COUNTING MEASUREMENTS

  94 ANALOG MEASUREMENTS

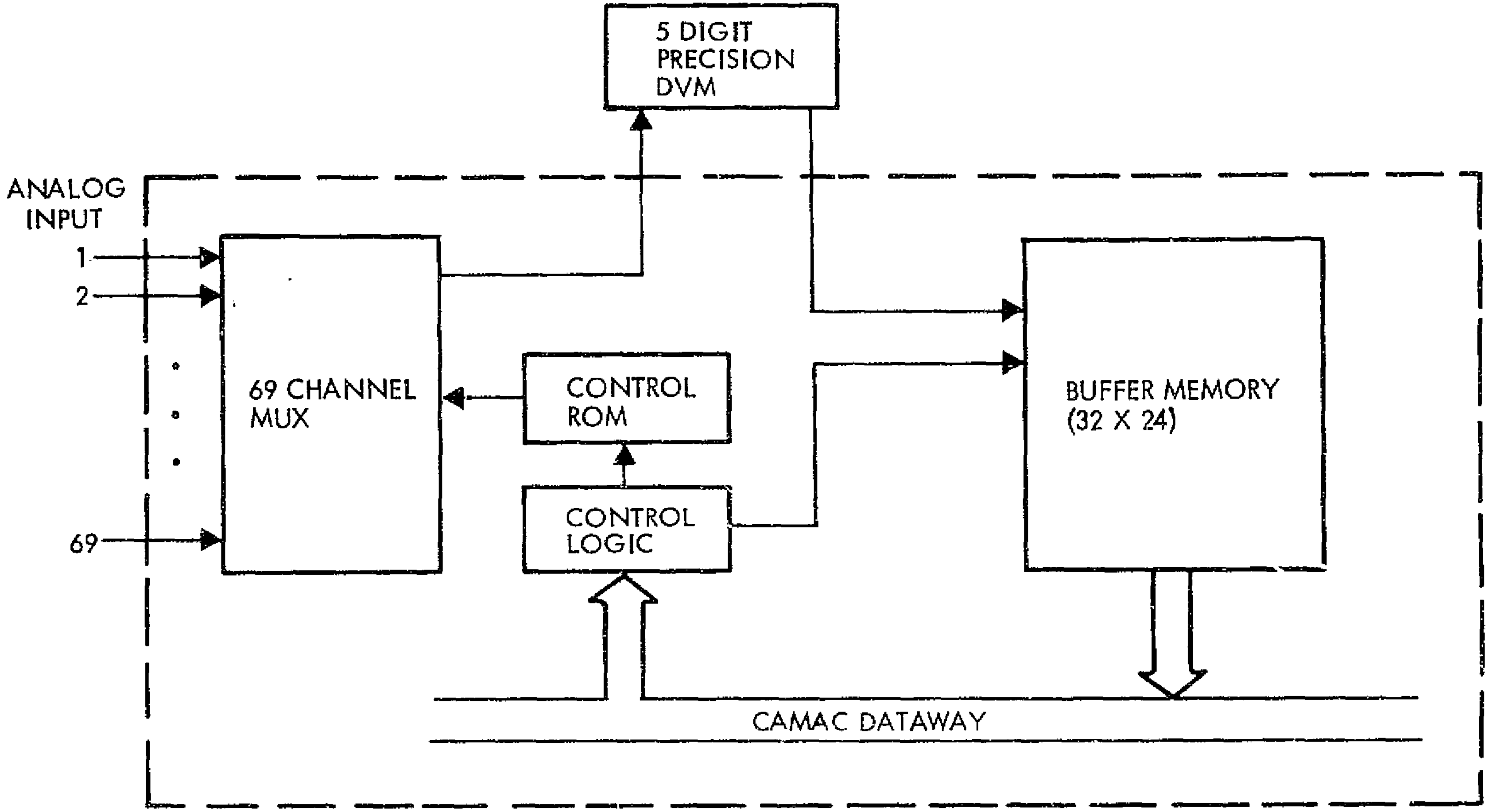
- DISCRETE MEASUREMENTS ARE MADE BY 32 (7 SPARE) RAU FLEXIBLE INPUTS
- PULSE COUNTING MEASUREMENTS ARE PERFORMED BY COMMERCIAL CAMAC SCALERS AND READ THROUGH THE RAU SERIAL DIGITAL LINK
- 32 RAU FLEXIBLE INPUTS (7 SPARE) ARE USED FOR LOW RESOLUTION ANALOG DATA
- HIGH RESOLUTION ANALOG DATA (69 CHANNELS) IS PROCESSED BY A PRECISION DVM AT RATES OF 32 SAMPLES PER SECOND

TRW

The precision analog data system allows the measurement of temperatures to be resolved to approximately 10^5 (16 bits) of full scale. To save hardware the precision DVM is also used to sample the medium resolution data (i.e., 10 to 12 bits) by multiplexing the inputs with a computer selected sampling routine.

CONTROL AND DATA SUBSYSTEM

PRECISION ANALOG DATA SYSTEM



- PRECISION DVM PROVIDES A MEASUREMENT RESOLUTION OF 10^5
- TEMPERATURE MEASUREMENTS CAN BE RESOLVED TO 0.001°C
- SYSTEM CAN SAMPLE AT A RATE OF 32/SEC
- MEASUREMENT SEQUENCE IS PROGRAMMABLE FROM COMPUTER

TRW

A wide variety of electromechanical, electronic and optical equipment require control signals from the Control and Data Subsystem.

CONTROL AND DATA SUBSYSTEM

ACPL CONTROL

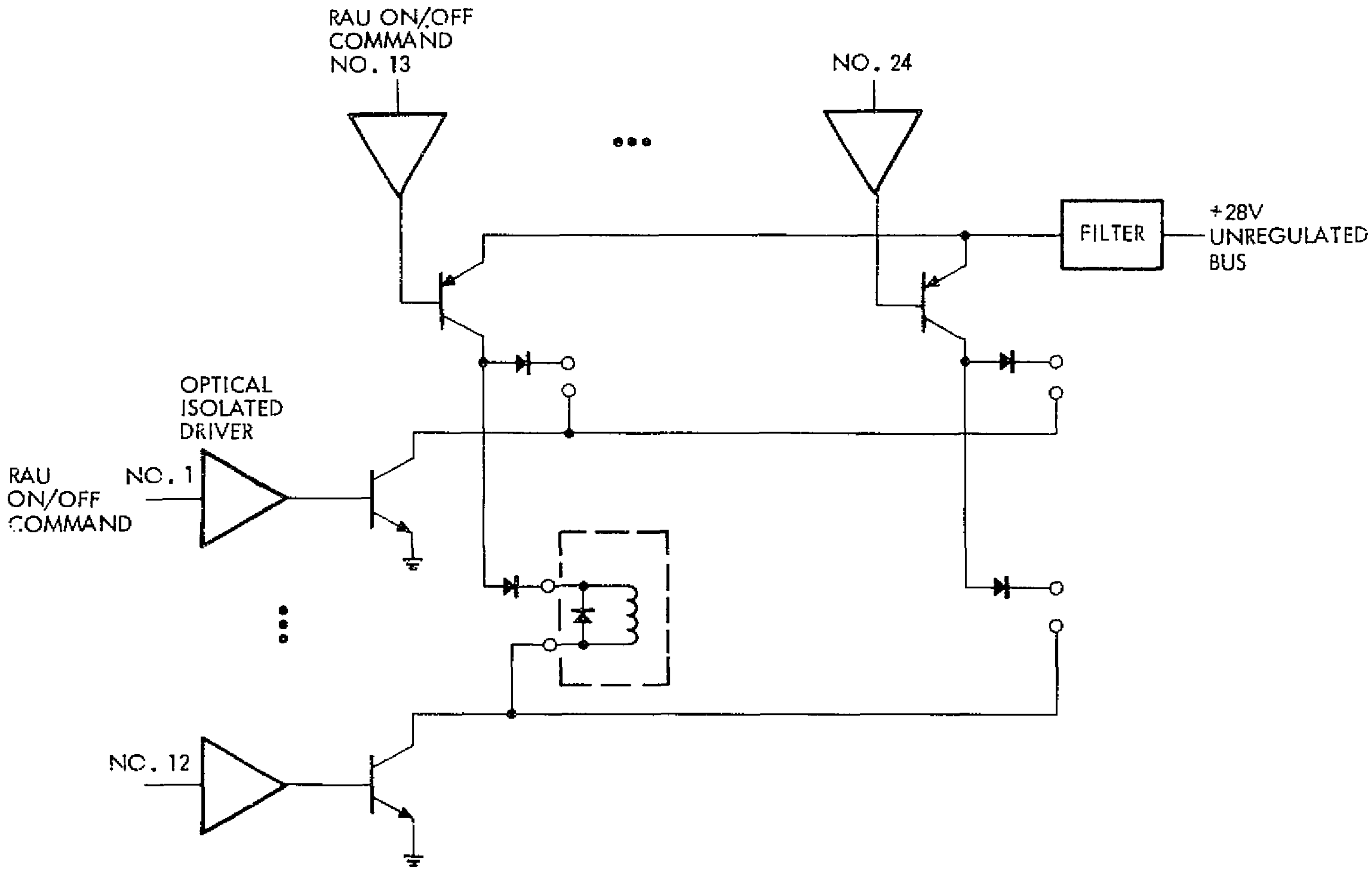
41	2-WAY VALVES	1	OPTICAL PARTICLE DET AND PHA
15	3-WAY VALVES	1	ELECTRONIC AEROSOL ANALYZER
12	PUMPS	1	ELECTRONIC AEROSOL SAMPLER
16	HEATERS	1	CLASSIFIER
2	SERVO VALVES	1	NaCl GENERATOR
1	FAN	1	H_2SO_4 GENERATOR
2	CAMERAS	16	POWER SUPPLIES
2	FLASHTUBES	192	TE MODULES
2	COMPUTER CONTROLLED VALVES	1	OPERATOR PANEL

- MOST ITEMS REQUIRE ONLY ON/OFF CONTROL
- TWENTY SEVEN (27) ITEMS REQUIRE FEEDBACK CONTROL

TRW SYSTEMS GROUP

Power and valve control is done with a 12x12 switching matrix. The matrix provides control for 144 loads with only 24 discrete drivers. The 144 loads are under direct control of the RAU discrete ON/OFF command outputs.

CONTROL AND DATA SUBSYSTEM
POWER SWITCHING AND VALVE CONTROL MATRIX



- 24 RAU ON/OFF COMMAND CONTROLS 144 COILS
- MATRIX CONFIGURATION MINIMIZES ACPL HARDWARE
- OPTICAL ISOLATED DRIVERS ALLOWS USE OF UNREG +28V FOR MINIMUM POWER

TRW

The operation of ACPL requires the use of 27 control loops. Set point adjustment is performed manually for four of the control loops and by computer control via the CAMAC dataway for 23 controllers.

CONTROL AND DATA SUBSYSTEM
ACPL CONTROL LOOPS

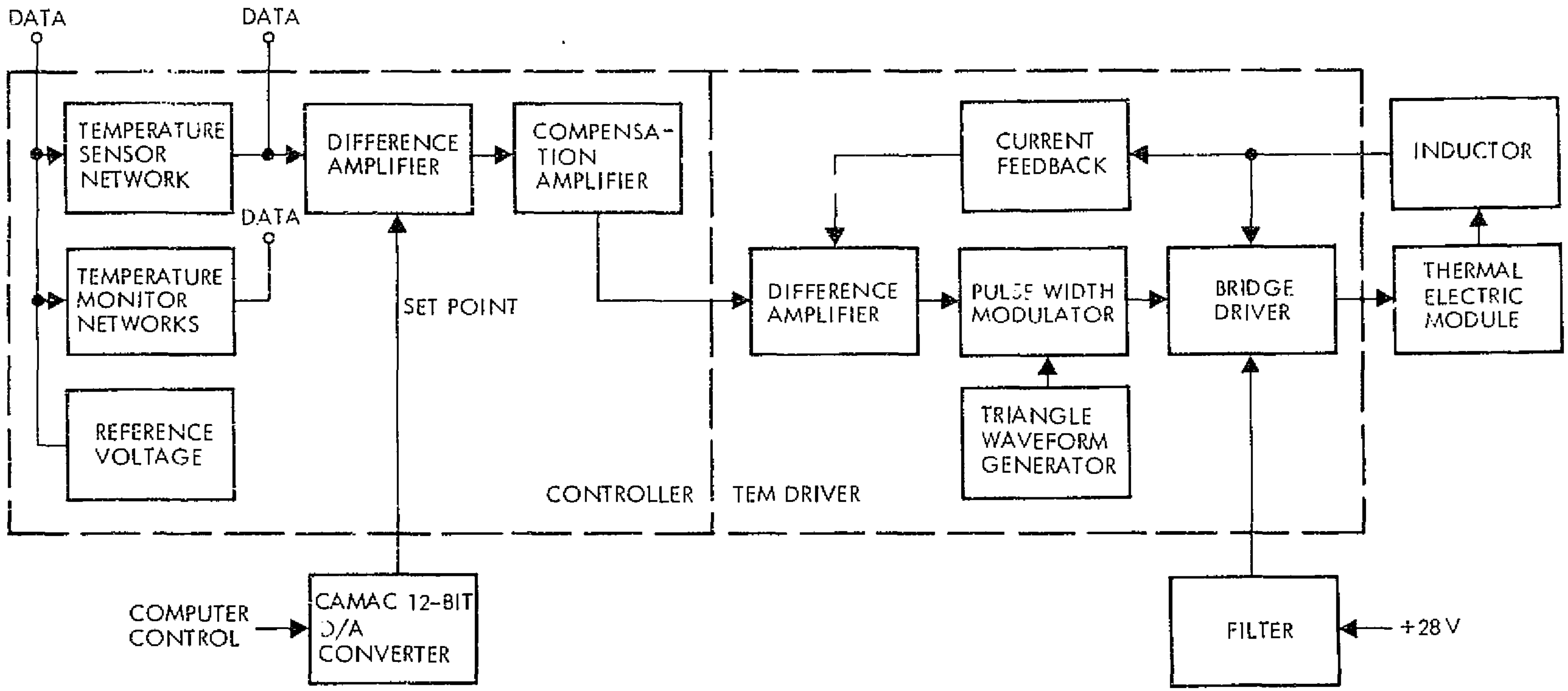
DESCRIPTION	TYPE	CONTROLLED COMPONENT	SET POINT GENERATOR	NUMBER REQUIRED
SATURATOR	TEMPERATURE, HEAT AND COOL	THERMOELECTRIC	PROGRAMMABLE, 12-BITS	1
CFD HOT PLATE	TEMPERATURE, HEAT AND COOL	THERMOELECTRIC	PROGRAMMABLE, 12-BITS	1
CFD COLD PLATE	TEMPERATURE, HEAT AND COOL	THERMOELECTRIC	PROGRAMMABLE, 12-BITS	1
SDL HOT PLATE	TEMPERATURE, HEAT AND COOL	THERMOELECTRIC	PROGRAMMABLE, 12-BITS	1
SDL COLD PLATE	TEMPERATURE, HEAT AND COOL	THERMOELECTRIC	PROGRAMMABLE, 12-BITS	1
EXPANSION CHAMBER OUTER WALL	TEMPERATURE, COOL	THERMOELECTRIC	PROGRAMMABLE, 12-BITS PLUS 2 CONTROL BITS	1
SATURATOR REHEAT	TEMPERATURE, HEAT	HEATER	PRESET ADJUSTABLE	1
EXPANSION CHAMBER INNER WALL	TEMPERATURE, HEAT	HEATER	PROGRAMMABLE, 12-BITS PLUS 6 BIT RATE	11
EXPANSION CHAMBER WINDOWS AND PORTS	TEMPERATURE, HEAT	HEATER		4
PLENUM 1	PRESSURE, ABSOLUTE	PUMP	PRESET	1
EXPANSION CHAMBER	PRESSURE, ABSOLUTE	SERVO-VALVE	PRESET	1
INTERPLENUM BLEED	PRESSURE, DIFFERENTIAL	SERVO-VALVE	PRESET	1
CFD	FLOW	COMPUTER CONTROLLED VALVE	PROGRAMMABLE	2

TRW

The thermal electric module controllers use unregulated 28 volt power to minimize control power losses. Isolation is achieved using transformer coupling. Current filtering is used to increase TE efficiency.

CONTROL AND DATA SUBSYSTEM

THERMOELECTRIC MODULE CONTROLLER



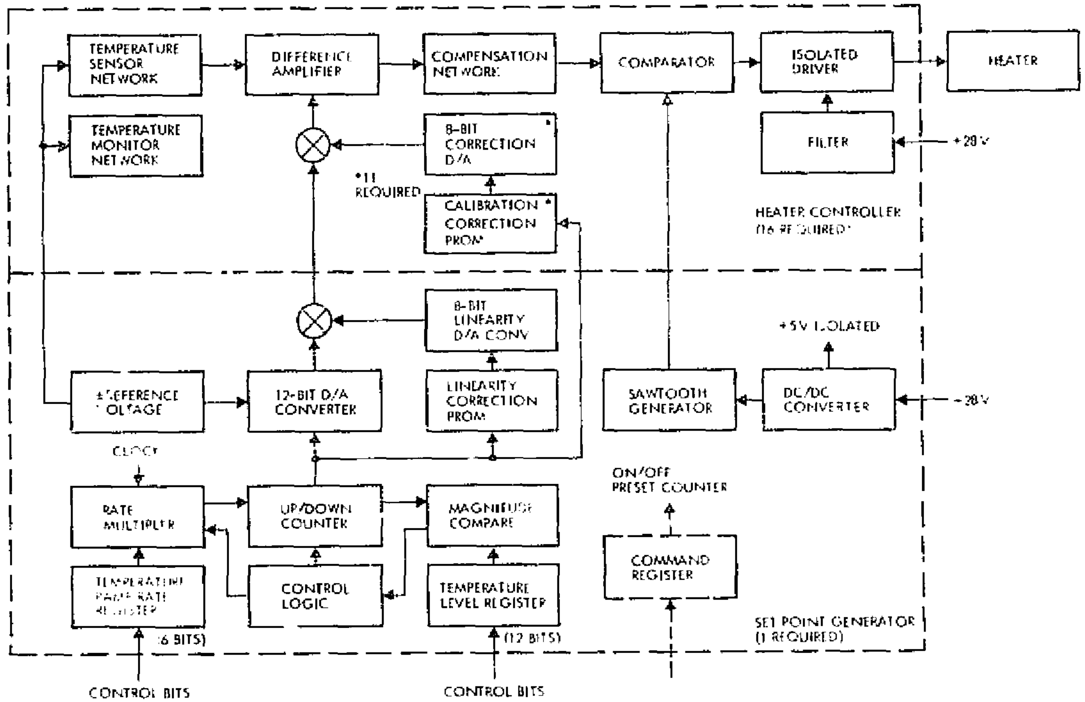
- THERMOELECTRIC MODULE FOR BOTH HEATING AND COOLING
- PROGRAMMABLE TEMPERATURE
- MINIMUM POWER
  - PULSE WIDTH MODULATED DRIVER
  - TEM POWER FROM UNREGULATED +28 V BUS
- INDUCTANCE INCLUDED TO MINIMIZE RIPPLE CURRENT
- CURRENT FEEDBACK ATTENUATES +28V BUS VARIATION EFFECTS

TRW

The expansion chamber heater controllers (16) share a common set point controller which provides a controlled set point ramp without constant access to the computer. The ramp is delinearized to compensate for the non-linear characteristics of the sensor. In addition the 11 inner wall heater controllers have calibration correction PROM's to match the sensor characteristics. The controllers also share a common sawtooth comparison generator whose slope is proportional to the square of the bus voltage. The sawtooth generator thus provides loop gain correction for the bus voltage variations.

CONTROL AND DATA SUBSYSTEM

EXPANSION CHAMBER HEATER TEMPERATURE CONTROL



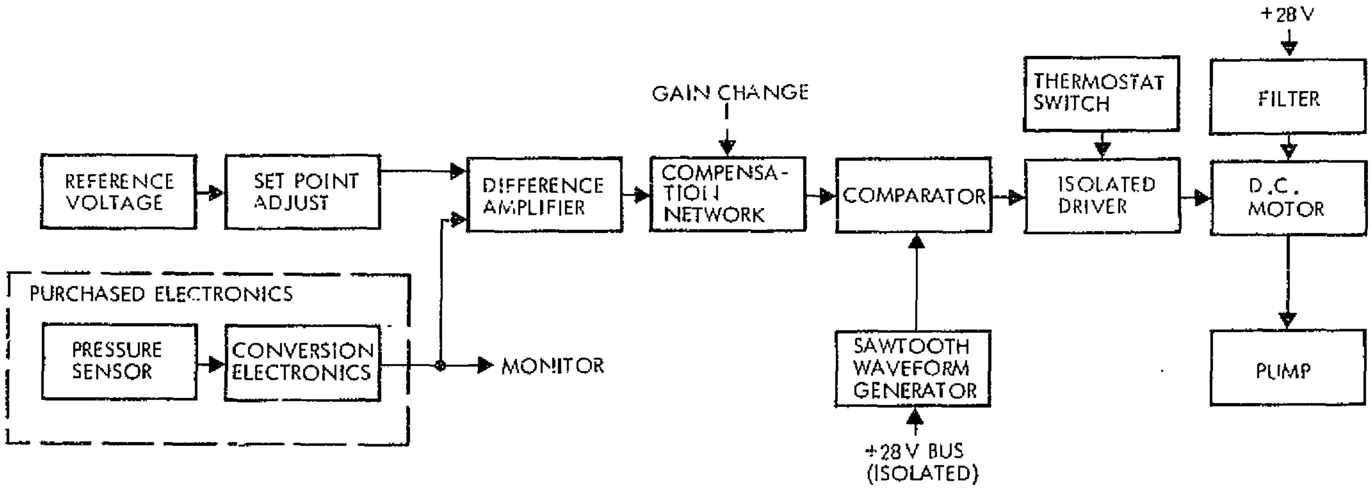
- MINIMUM POWER
  - PULSE WIDTH MODULATED DRIVER
  - POWER FROM UNREGULATED +28 V
- PWM SAWTOOTH WAVEFORM CORRECTED TO COMPENSATE FOR +28 V CHANGES
- PROGRAMMABLE TEMPERATURE LEVEL AND RAMP RATE
- QUASI-LINEAR TEMPERATURE SENSOR NETWORK RESPONSE
- LINEARITY CORRECTION STORED IN PROM
- SENSOR MISMATCH CORRECTION STORED IN PROM

TRW

The controller for the servo controlled pump uses the isolated bus voltage of the expansion chamber heater controller to drive its sawtooth generator and thus compensate for bus variation. The output driver is protected from overheating due to motor stall.

CONTROL AND DATA SUBSYSTEM

SERVO-CONTROL PUMP PRESSURE CONTROL BLOCK DIAGRAM

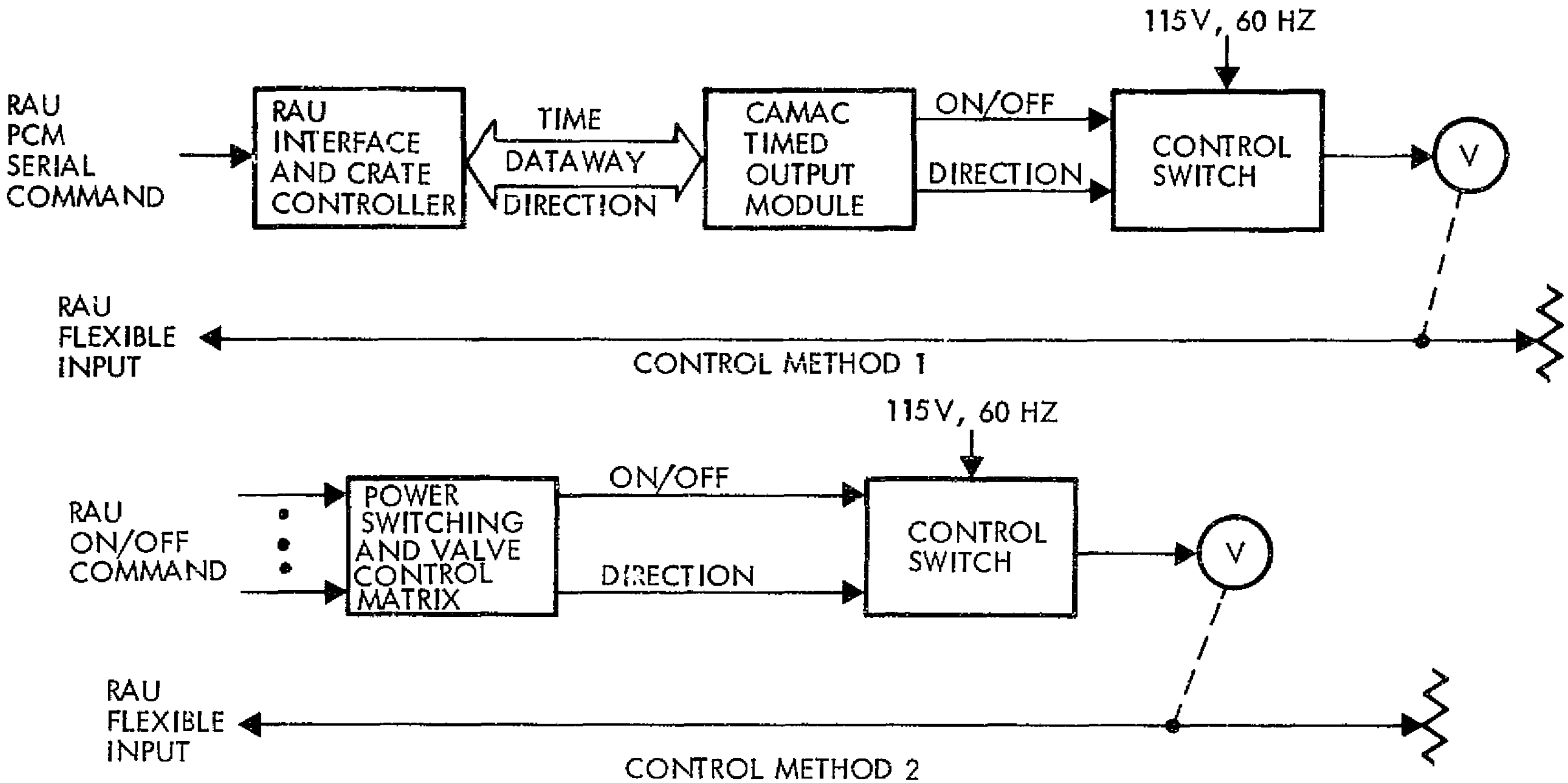


- DC MOTOR FOR PUMP SPEED CONTROL
- LEAD LAG COMPENSATION
- MINIMUM POWER
  - PULSE WIDTH MODULATED DRIVER
  - MOTOR POWER FROM UNREGULATED +28 VOLT BUS
- SAWTOOTH WAVEFORM CORRECTED TO COMPENSATE FOR +28 VOLT CHANGE
- OUTPUT DRIVER OVER TEMPERATURE PROTECTION
- GAIN SWITCHING FOR OPTIMUM VALVE SWITCHING TRANSIENT RESPONSE MIGHT BE INCLUDED.

TRW

CONTROL AND DATA SUBSYSTEM

COMPUTER CONTROLLED VALVES



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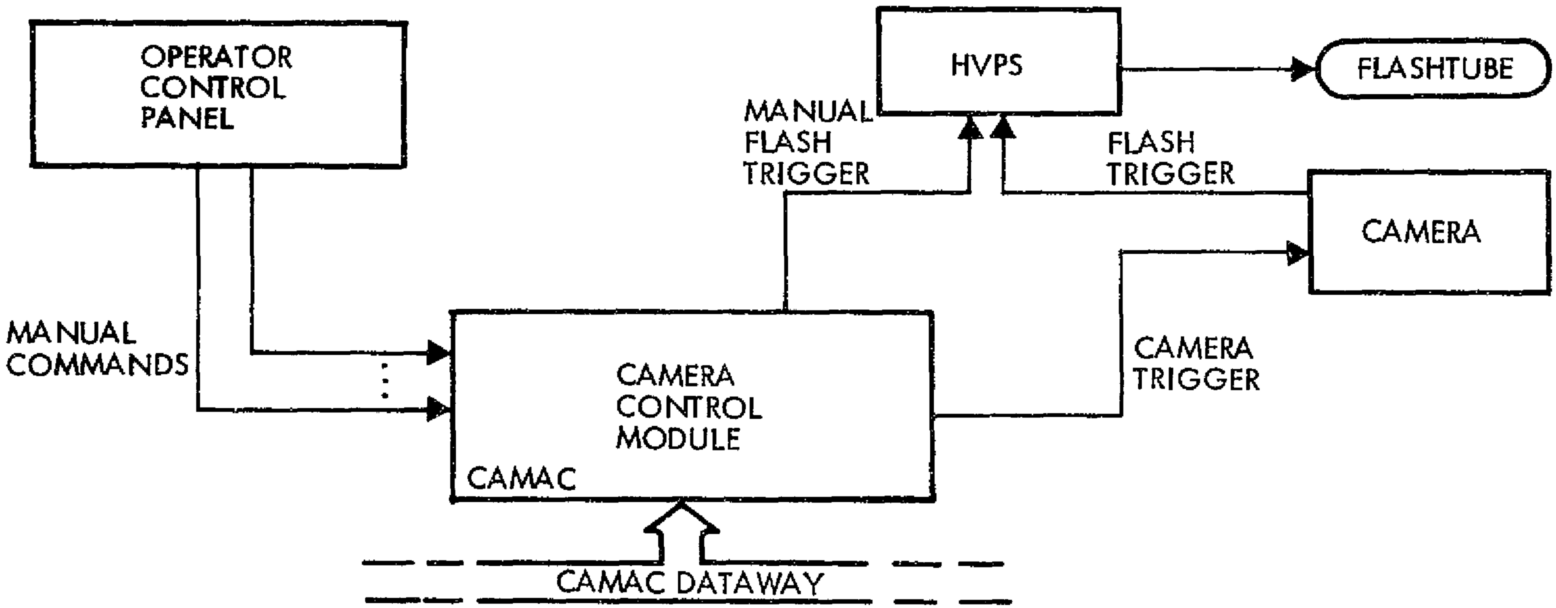
TRW

The cameras and flashtubes on ACPL can operate either through computer commands or with manual commands via the Operator Control panel. The camera and flashtube control module allows frame rates of 3 per second, 1 per second or single shot. The flashtube is controlled by the camera trigger output for picture taking or manually for visual observation in the chamber.

CONTROL AND DATA SUBSYSTEM

OPTICAL AND IMAGING CONTROL



- OPTICAL AND IMAGING CONTROL FROM S/L COMPUTER OR OPERATOR PANEL
- FLASHTUBE CONTROLLED BY CAMERA TRIGGER OR BY MANUAL TRIGGER
- CAMERA FRAME RATES OF 3/SEC, 1/SEC OR SINGLE SHOT

TRW

The Operator Control Panel provides two 5-1/2 digit readouts which can display any ACPL measurement made by the computer. The measurements to be displayed are selected at the panel by BCD switches. The switches are periodically sampled by the computer and the requested data is returned through the serial PCM link to a holding register which drives the displays.

CONTROL AND DATA SUBSYSTEM

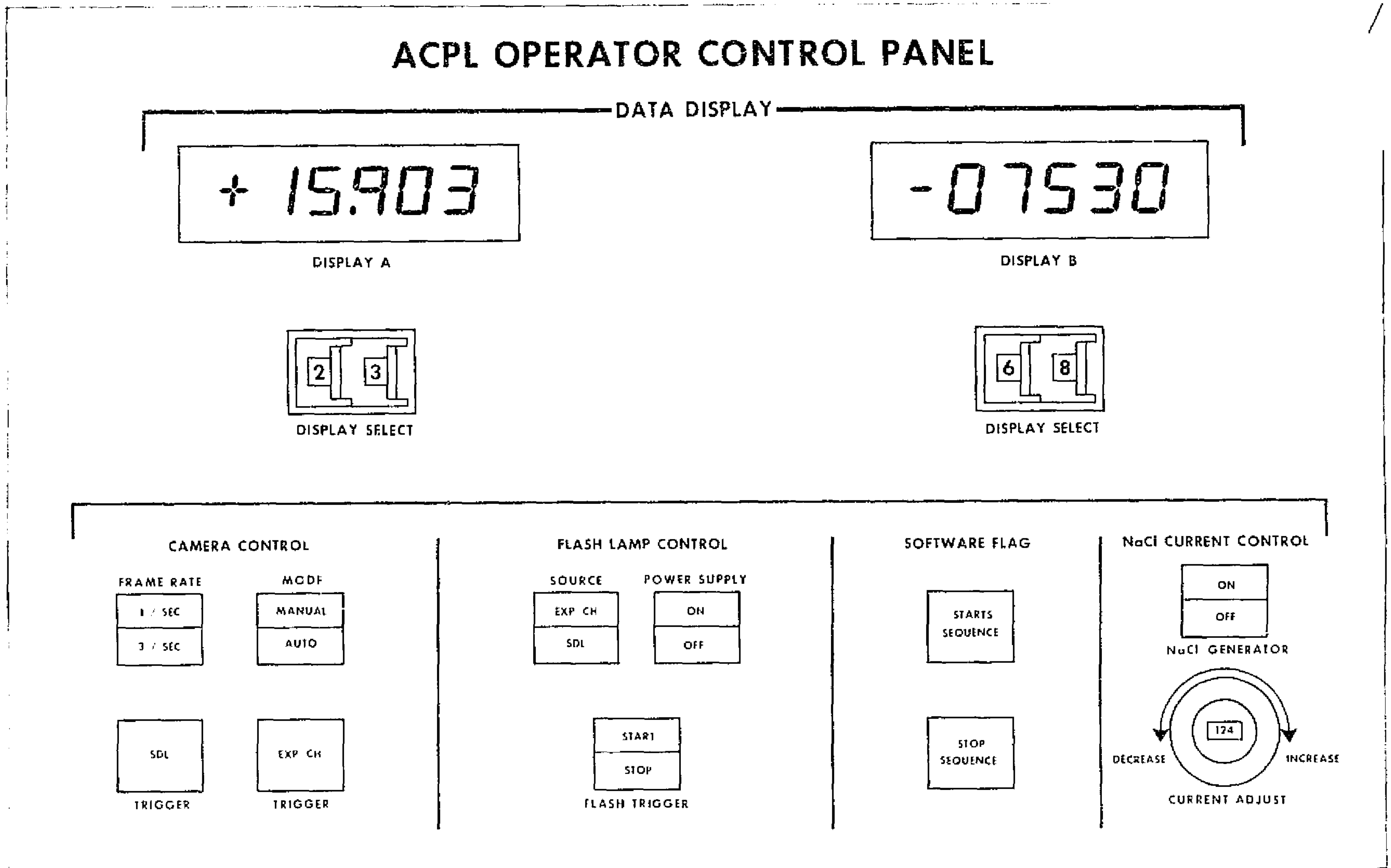
OPERATOR CONTROL PANEL

- PROVIDES DUAL SELECTABLE READOUTS FOR ACPL DATA
- CAPABLE OF DISPLAYING 200 DIFFERENT PARAMETERS
- COMPLETE CAMERA CONTROL IS PROVIDED ON PANEL
- INDEPENDENT FLASHTUBE CONTROL PROVIDED FOR CHAMBER ILLUMINATION
- $NaCl$ GENERATOR CURRENT IS MANUALLY SELECTABLE
- SOFTWARE FLAG SWITCHES ALLOW COMPUTER SEQUENCES TO BE CONTROLLED FROM ACPL CONSOLE

TRW

Possible layout of controls and displays for the Operator Control Panel.

CONTROL AND DATA SUBSYSTEM



TRW

CONSOLE SUBSYSTEM

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TRW

The Console Subsystem integrates the other ACPL subsystems into a Spacelab standard double rack. It consists of the double rack, structural mounting hardware, electrical power supplies, power distribution cables, and a wick storage reservoir.

CONSOLE SUBSYSTEM

FUNCTION:

- CONDITION AND DISTRIBUTE SPACELAB ELECTRICAL POWER USED BY OTHER ACPL SUBSYSTEMS.
- INTEGRATE AND MECHANICALLY SUPPORT OTHER ACPL SUB-SYSTEMS IN STANDARD SPACELAB DOUBLE RACK.

APPROACH:

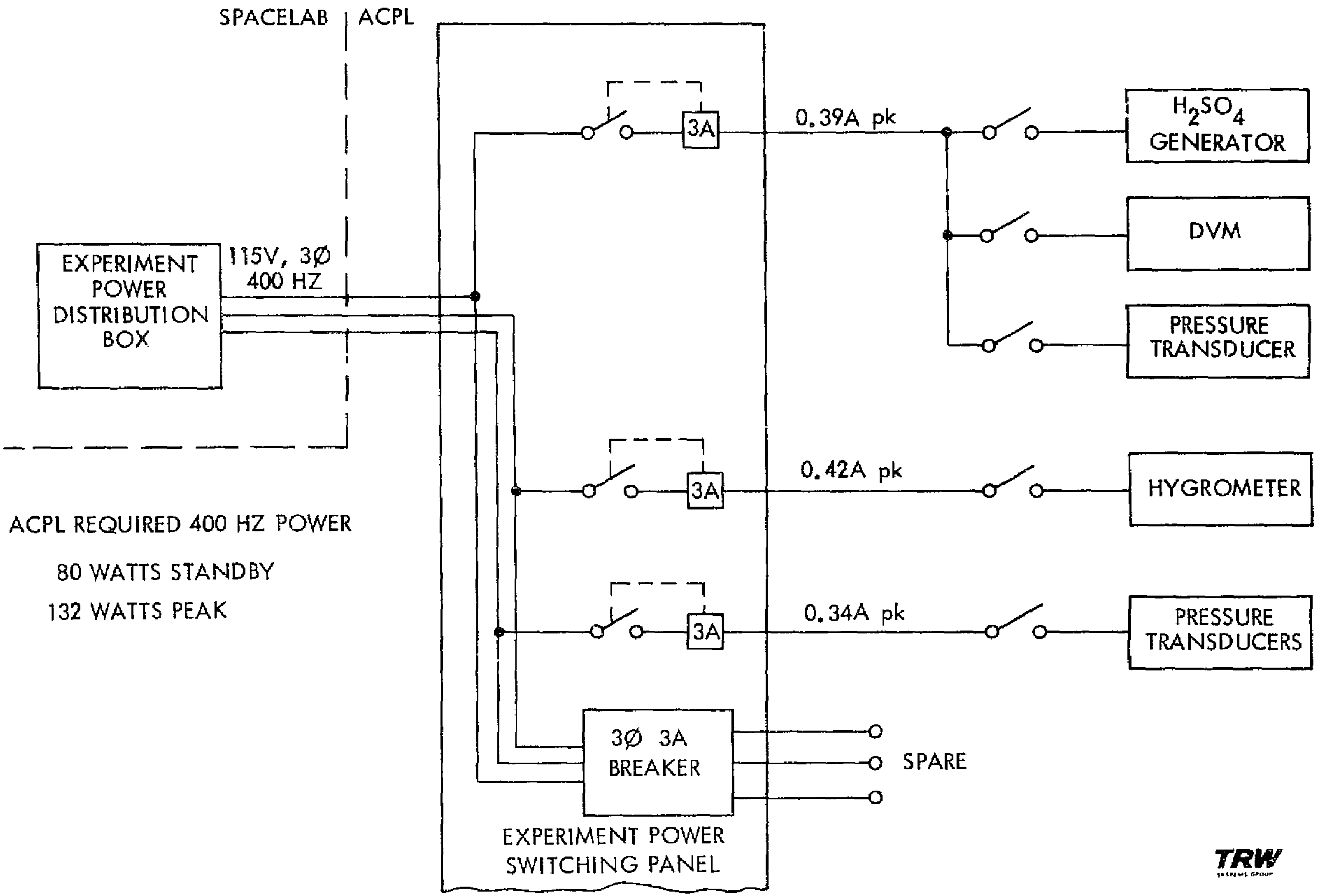
- MAXIMIZE USE OF UNREGULATED +28 V BUS. MINIMIZE USE OF 400 HZ BUS.
- REPLACE 115 V, 60 HZ POWER SUPPLIES WITH HIGH EFFICIENCY SWITCHING CONVERTERS RUN OFF +28 V BUS.
- PROVIDE FOR EXTENSIVE SUBSYSTEM POWER SWITCHING.
- OPERATE HIGH POWER LOADS DIRECTLY OFF THE +28 V BUS.
- INCORPORATE SUBSYSTEM EQUIPMENT INTO MODULES FOR EASE OF INTEGRATION, TESTING.
- CONSERVATIVE MECHANICAL DESIGN APPROACH FOR REDUCTION OF ANALYSIS AND VERIFICATION TESTING.

TRW

Power from the 400 Hz inverter is brought into ACPL through the EPSP. The ACPL 400 Hz loads are divided between the three phases for load equalization.

CONSOLE SUBSYSTEM

POWER DISTRIBUTION 115V, 400HZ INTERFACE



ACPL REQUIRED 400 HZ POWER

80 WATTS STANDBY

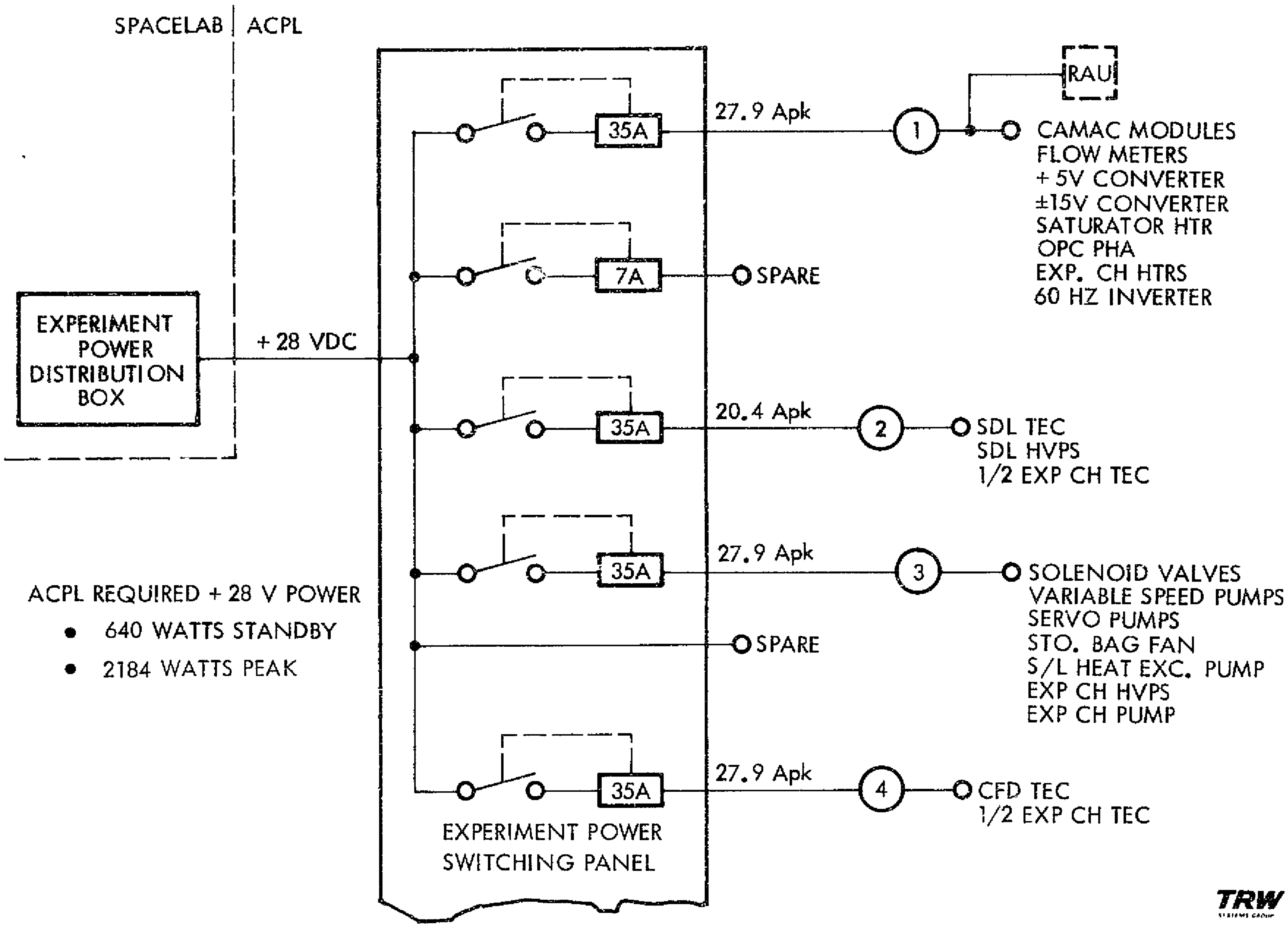
132 WATTS PEAK

TRW

The +28 V unregulated power usage in ACPL requires the use of all four of the 35A breakers in the EPSP to ensure adequate current margins during periods where the power requirement is high and the bus voltage is low (+24 V).

CONSOLE SUBSYSTEM

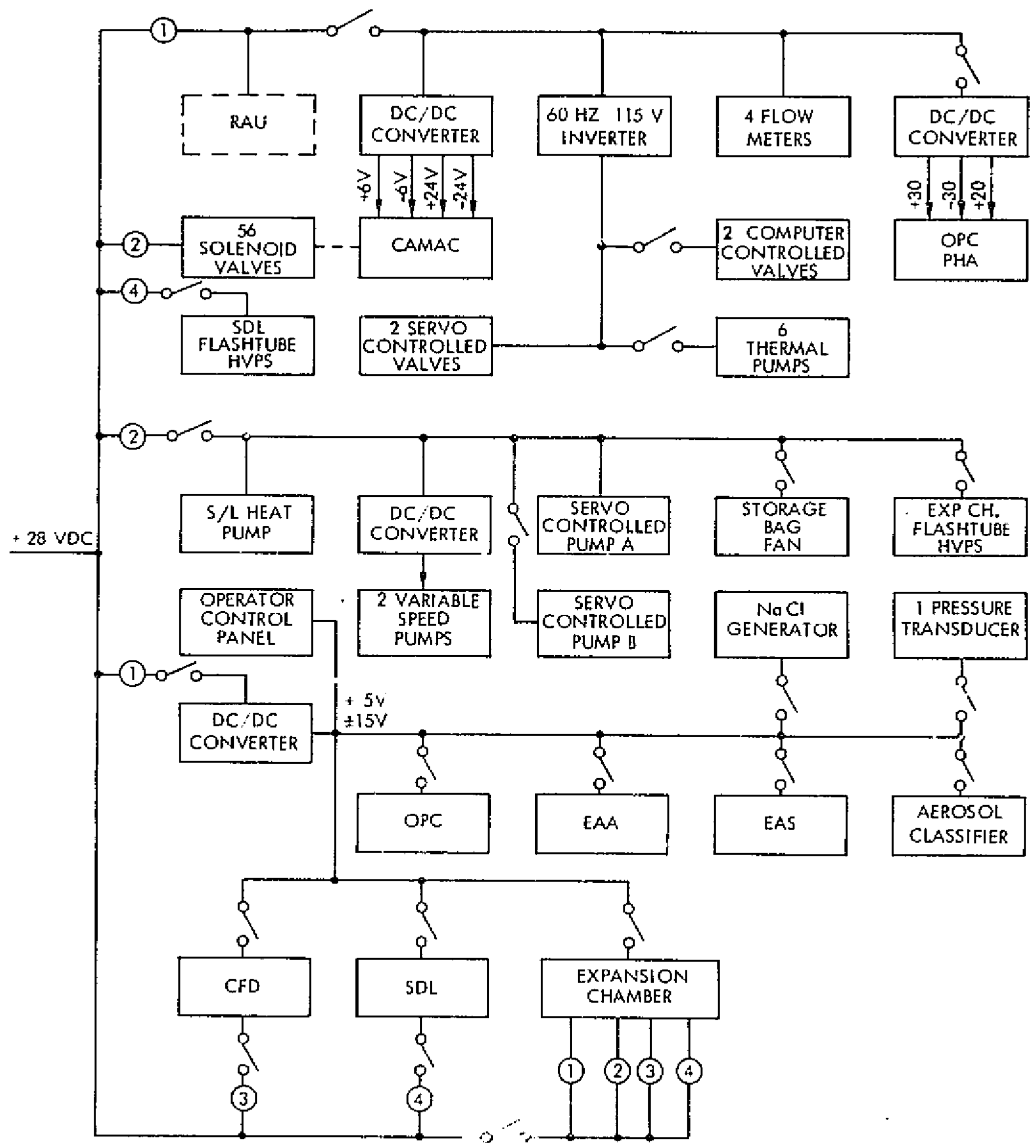
POWER DISTRIBUTION +28 VDC INTERFACE



TRW

Power to the ACPL subsystems is controlled by the computer. DC/DC converter voltages are shared between subsystems wherever possible to reduce hardware.

CONSOLE SUBSYSTEM
POWER DISTRIBUTION + 28V BUS DISTRIBUTION

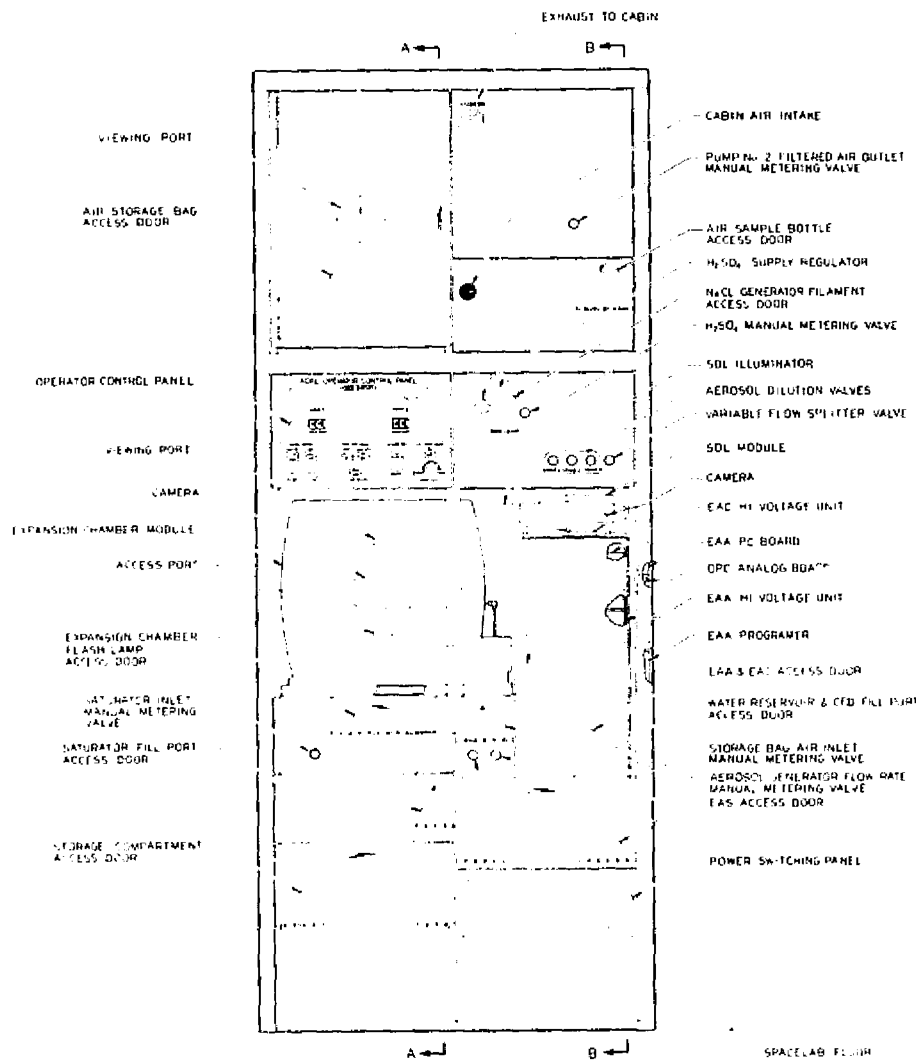


TRW

The packaging layout on the facing page shows the relative locations of the major ACPL equipment in a Spacelab standard double rack.

CONSOLE SUBSYSTEM

ATMOSPHERIC CLOUD PHYSICS LABORATORY ASSEMBLY

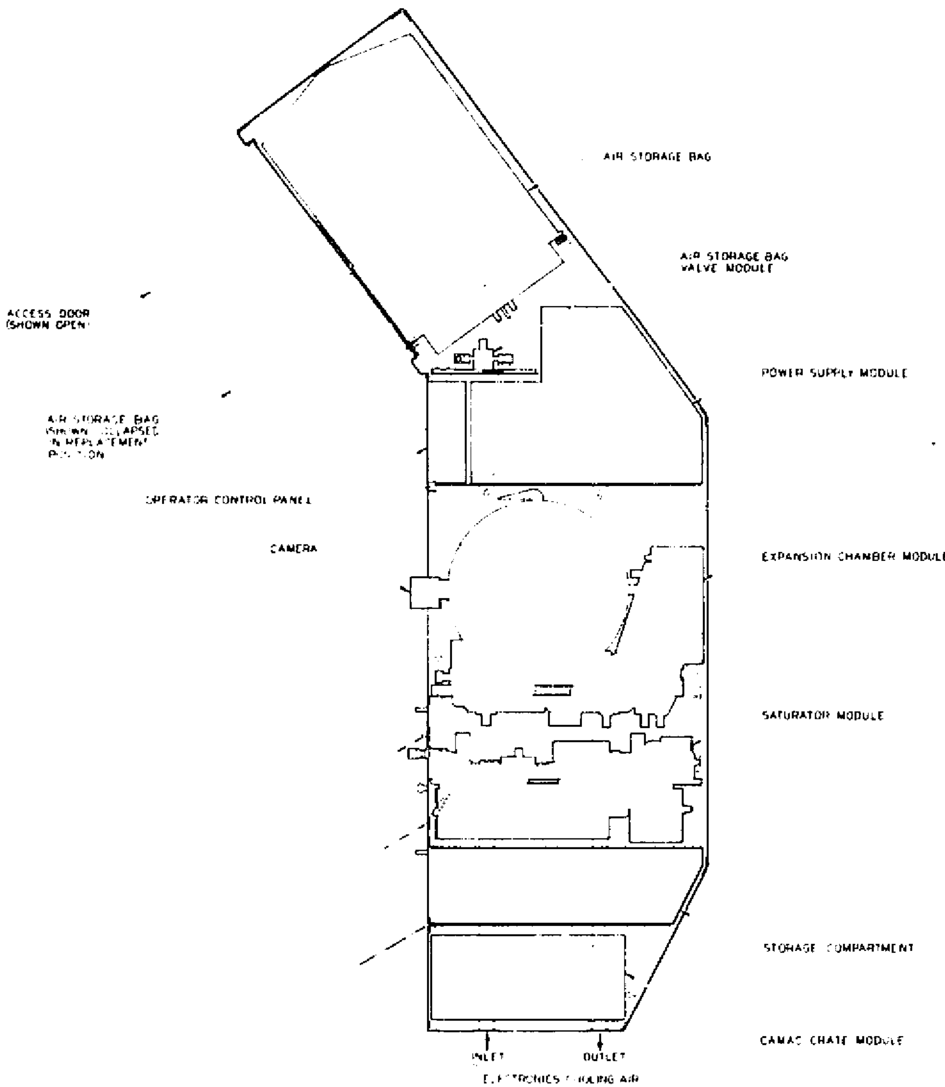


FRONT PANEL VIEW

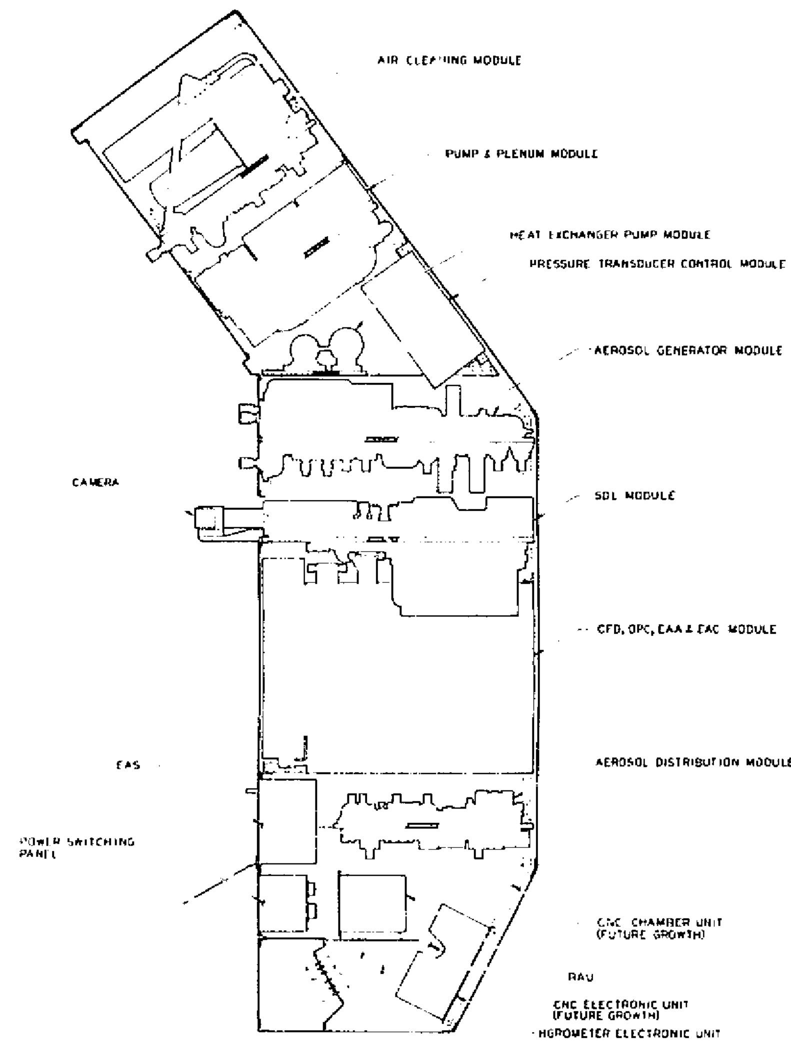
TRW

CONSOLE SUBSYSTEM

ACPL ASSEMBLY -CONTINUED



SECTION A-A



SECTION B-B

TRW SYSTEMS GROUP

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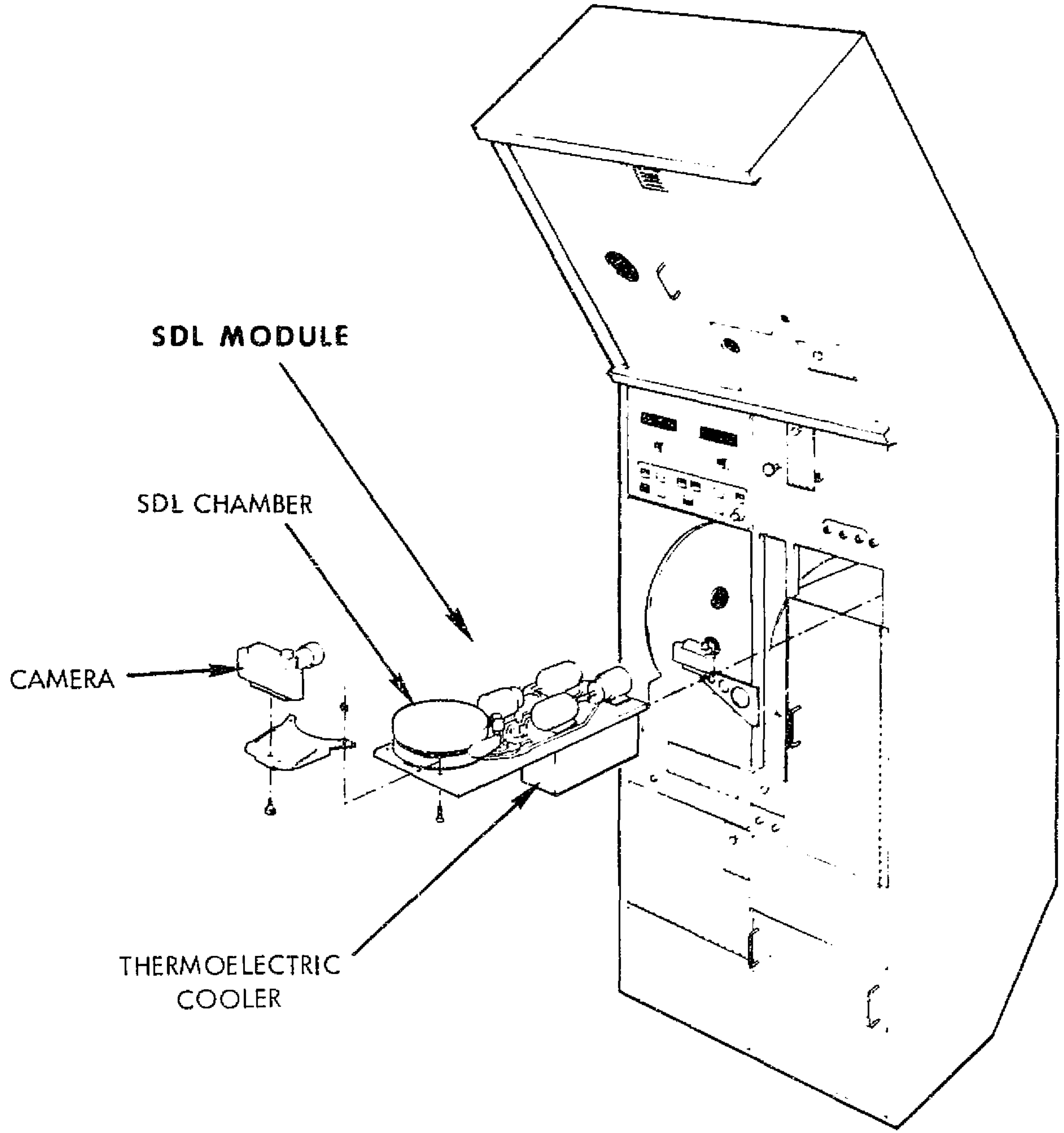
A key feature of the TRW packaging concept is the arrangement of components and subassemblies into modules which can easily be integrated into the Spacelab double rack. The facing page illustrates this approach showing the Static Diffusion Liquid (SDL) Module about to be inserted into the otherwise completed laboratory.

ACPL INTEGRATION SEQUENCE



TRW

The facing page identifies some key benefits derived from the modular packaging concept. Besides providing technical advantages, the approach contributes significantly to reducing total program costs.

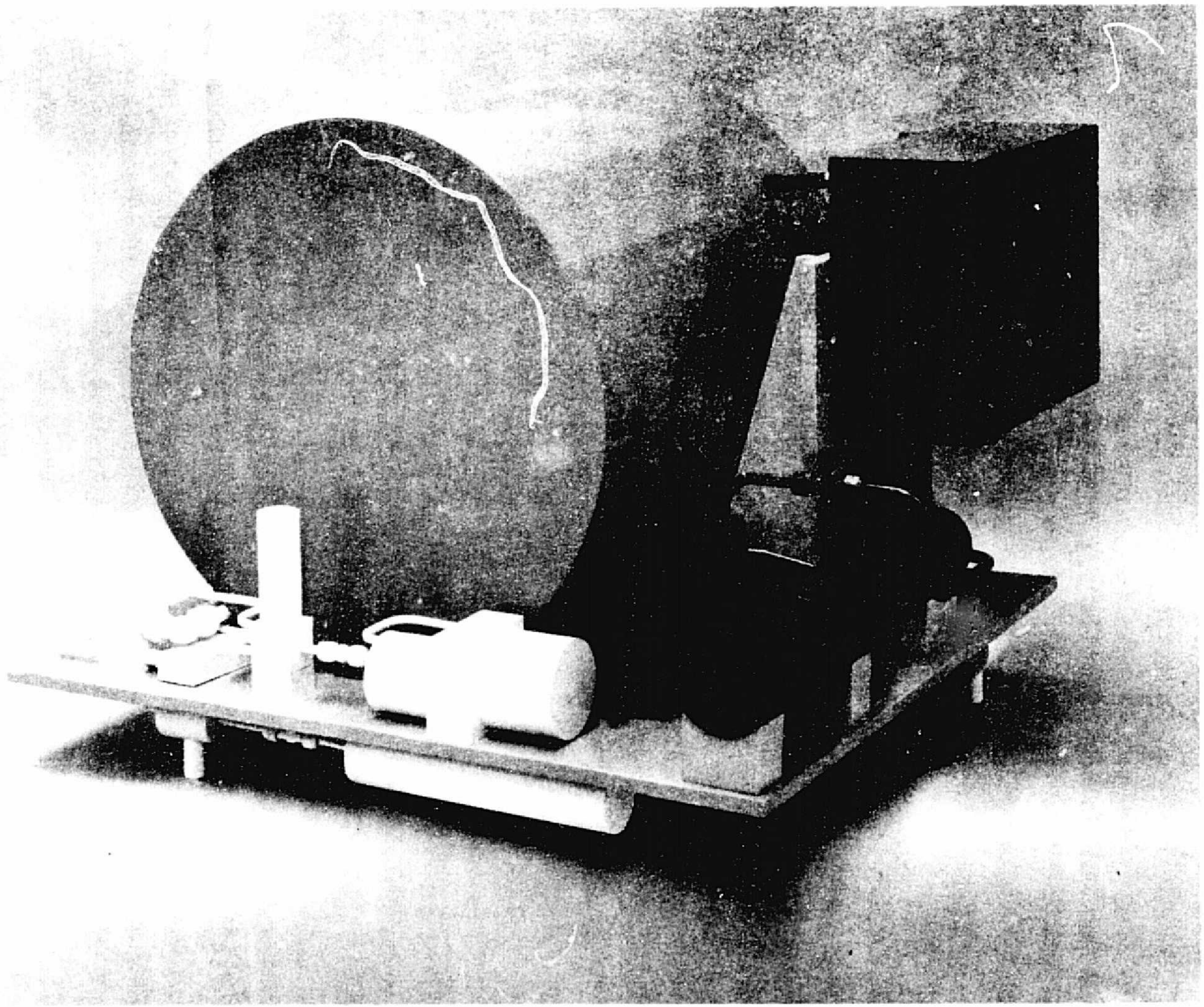
KEY FEATURES: ACPL PACKAGING CONCEPT

- EASES PROGRAM SCHEDULE BY PERMITTING PARALLEL MODULE BUILD-UP.
- THOROUGH MODULE CHECKOUT AND VERIFICATION TESTING REDUCES SYSTEM LEVEL PROBLEMS.
- MINIMUM IN-RACK PLUMBING, WIRING REDUCES INTEGRATION TIME, COSTS.
- SIMPLIFIES LABORATORY MAINTENANCE, REFURBISHMENT FOR NEXT FLIGHT.
- REDUCES SYSTEM LEVEL VERIFICATION TESTING (AND COSTS).
- MINIMIZES CRITICAL FLUID AND THERMAL LINE LENGTHS.
- PROVIDES MAXIMUM FLEXIBILITY FOR EVOLUTIONARY LABORATORY GROWTH.
- PERMITS STANDARDIZED SHELVES, MOUNTING BRACKETRY.

TRW

CONSOLE SUBSYSTEM

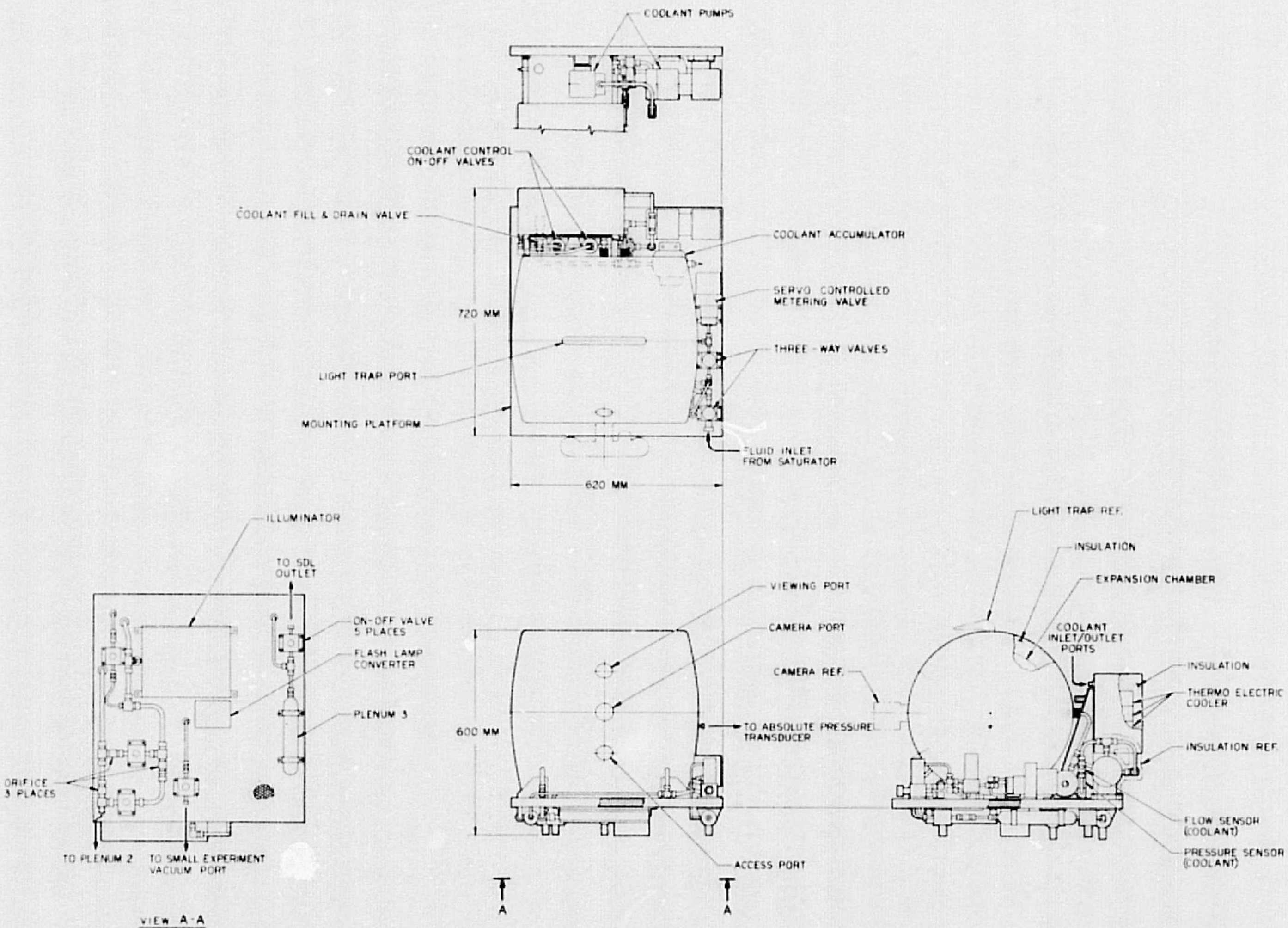
EXPANSION CHAMBER MODULE MOCK-UP



TRW
SYSTEMS GROUP

CONSOLE SUBSYSTEM

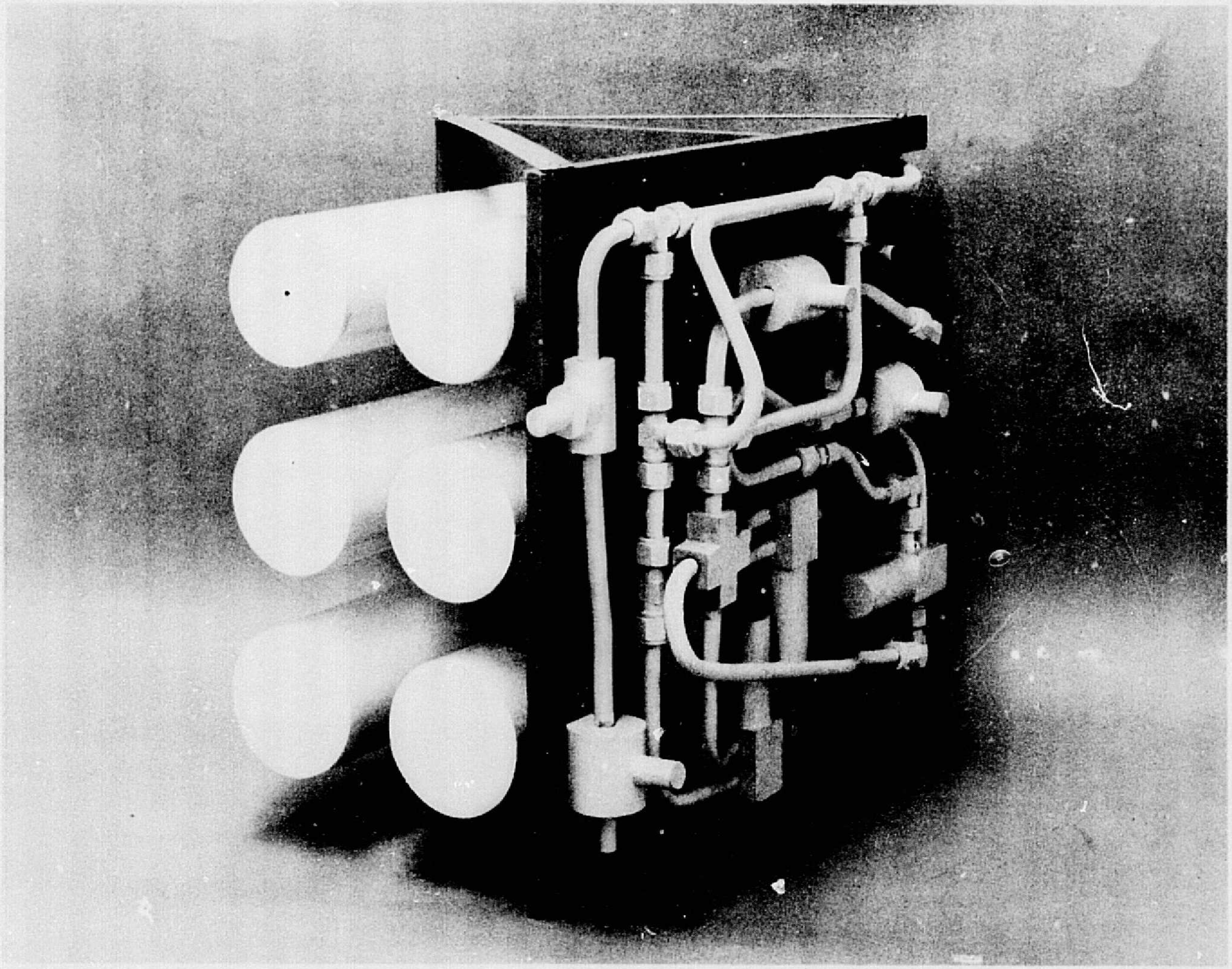
EXPANSION CHAMBER MODULE DRAWING



TRW SYSTEMS GROUP

CONSOLE SUBSYSTEM

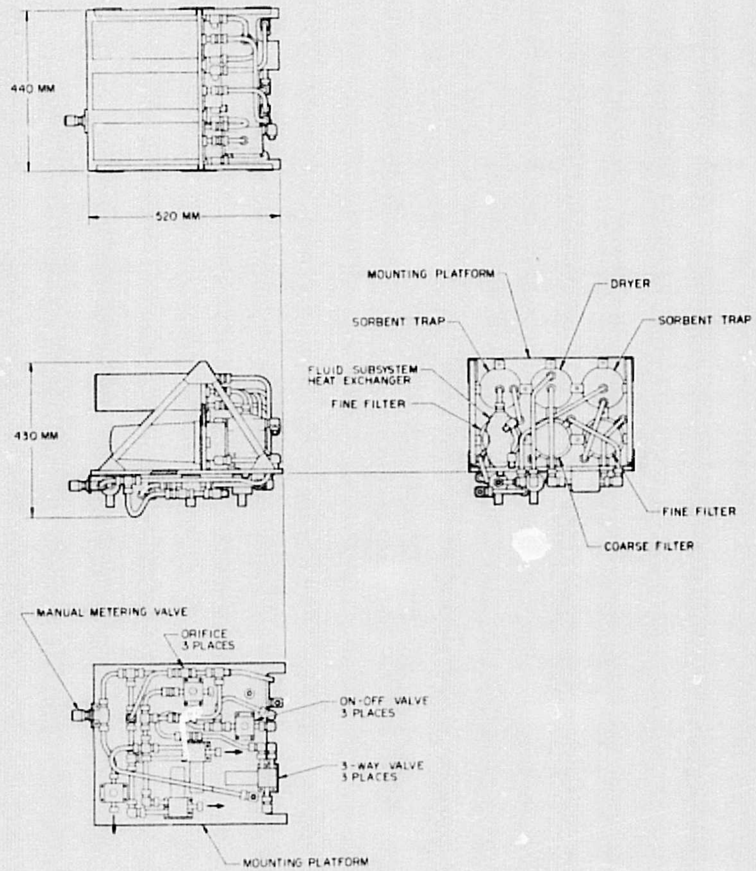
AIR CLEANING MODULE MOCK-UP



TRW
SYSTEMS GROUP

CONSOLE SUBSYSTEM

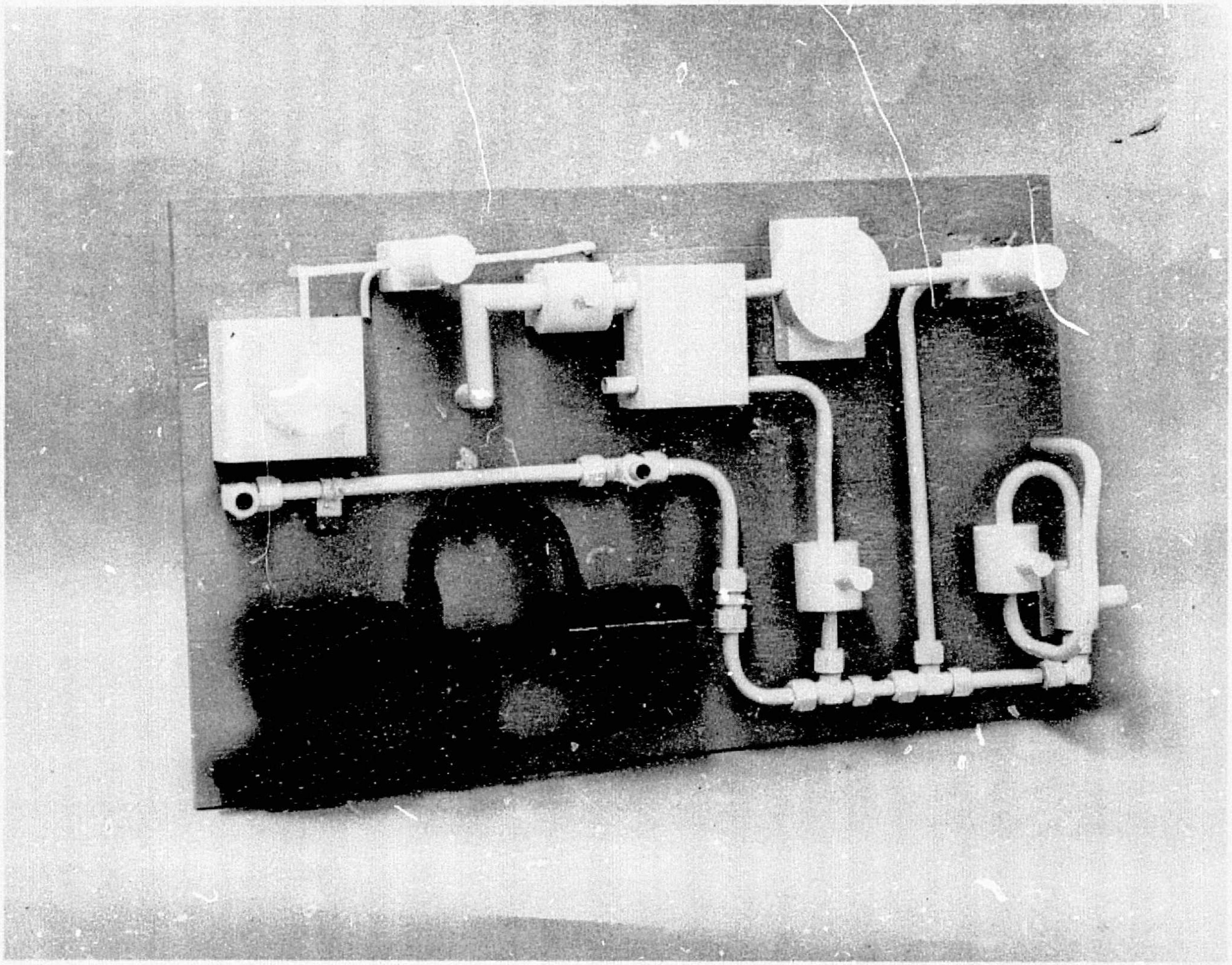
AIR CLEANING MODULE DRAWING



TRW
SYSTEMS GROUP

CONSOLE SUBSYSTEM

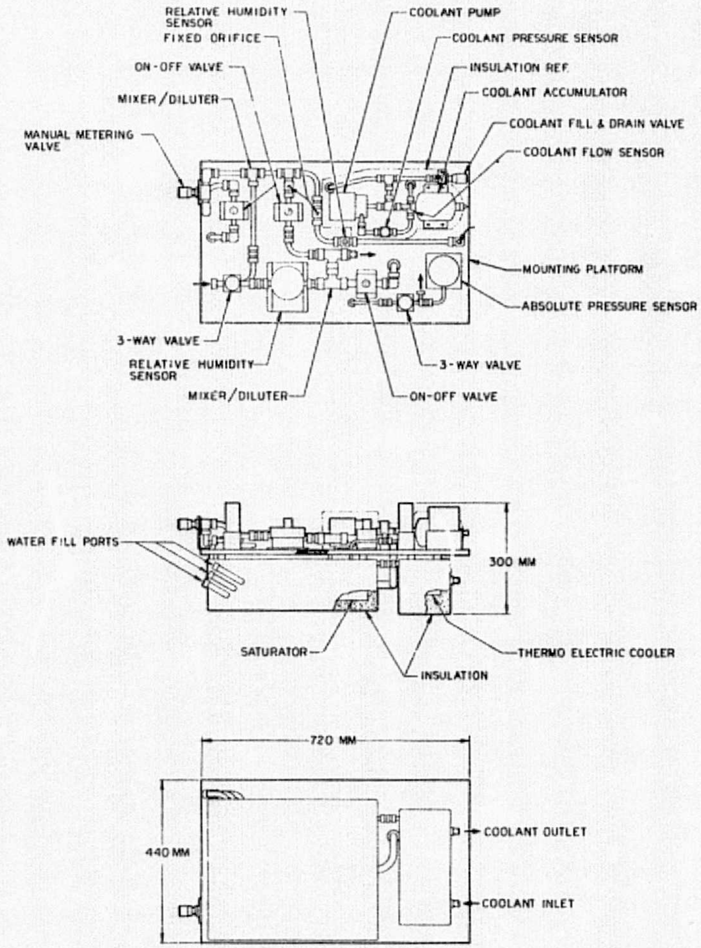
SATURATOR MODULE MOCK-UP



TRW
SYSTEMS GROUP

CONSOLE SUBSYSTEM

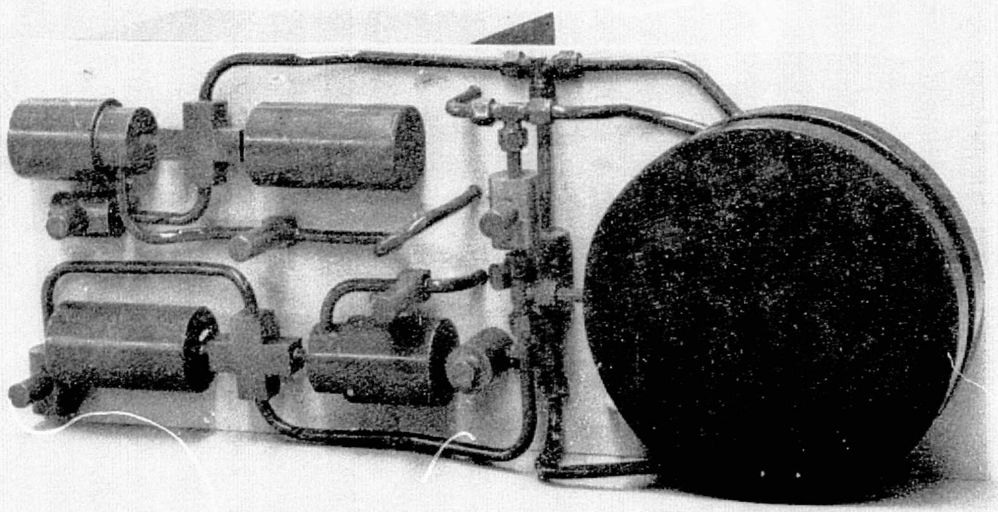
SATURATOR MODULE DRAWING



TRW
SYSTEMS GROUP

CONSOLE SUBSYSTEM

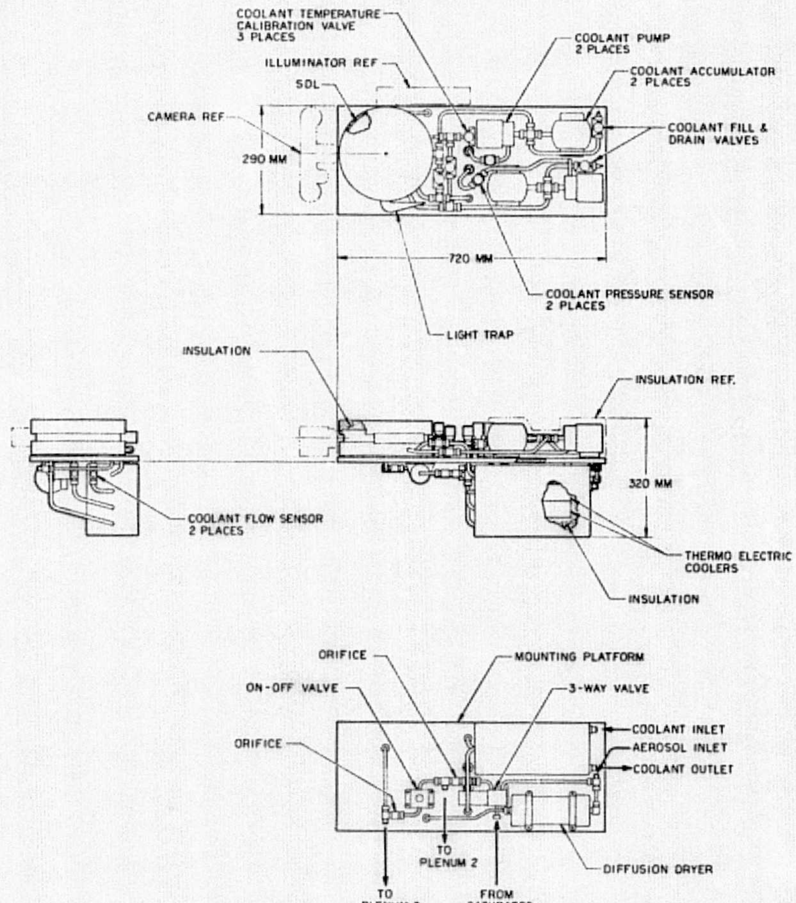
SDL CHAMBER MODULE MOCK-UP



TRW
SYSTEMS GROUP

CONSOLE SUBSYSTEM

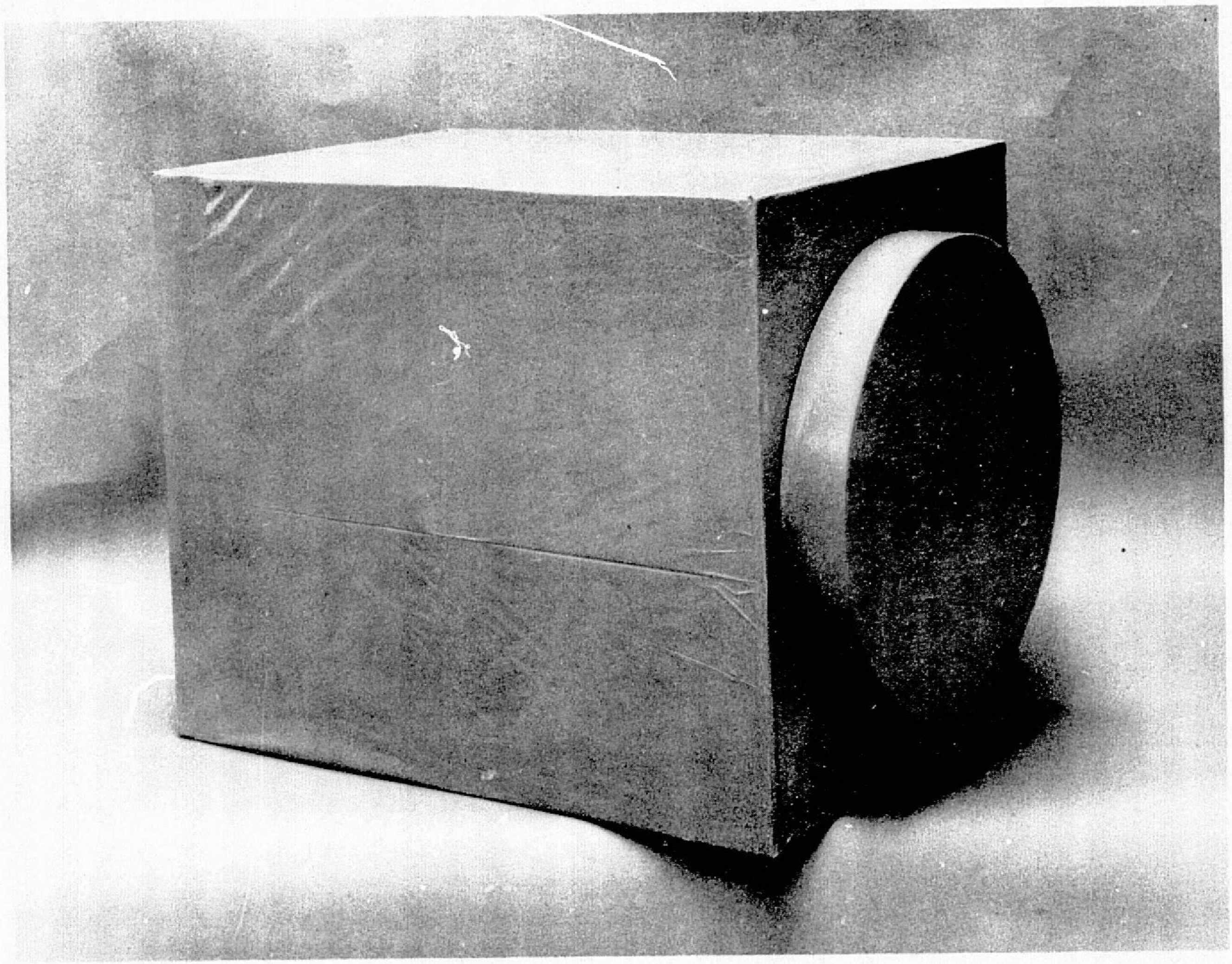
SDL CHAMBER MODULE DRAWING



TRW SYSTEMS GROUP

CONSOLE SUBSYSTEM

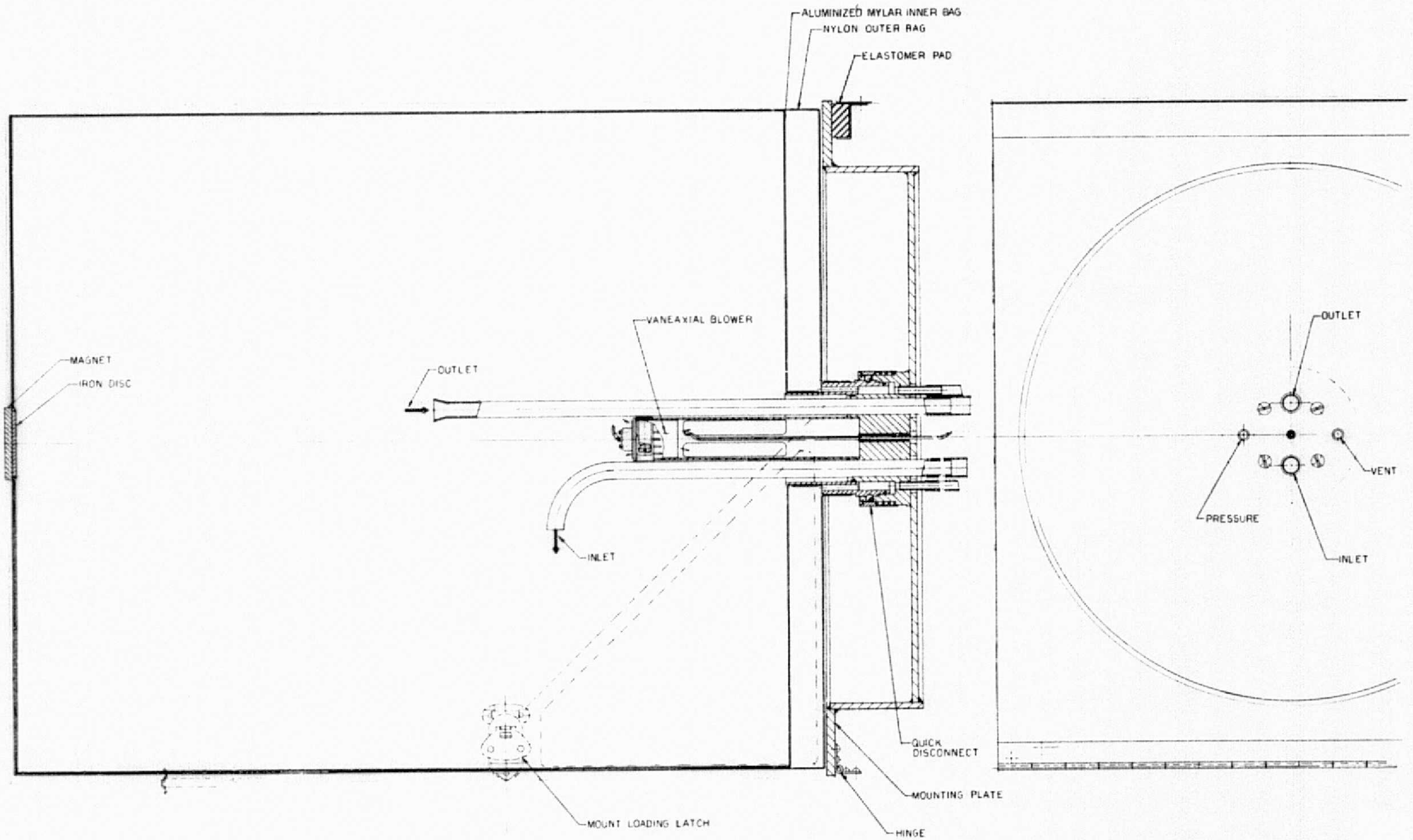
STORAGE BAG MODULE MOCK-UP



TRW
SYSTEMS GROUP

CONSOLE SUBSYSTEM

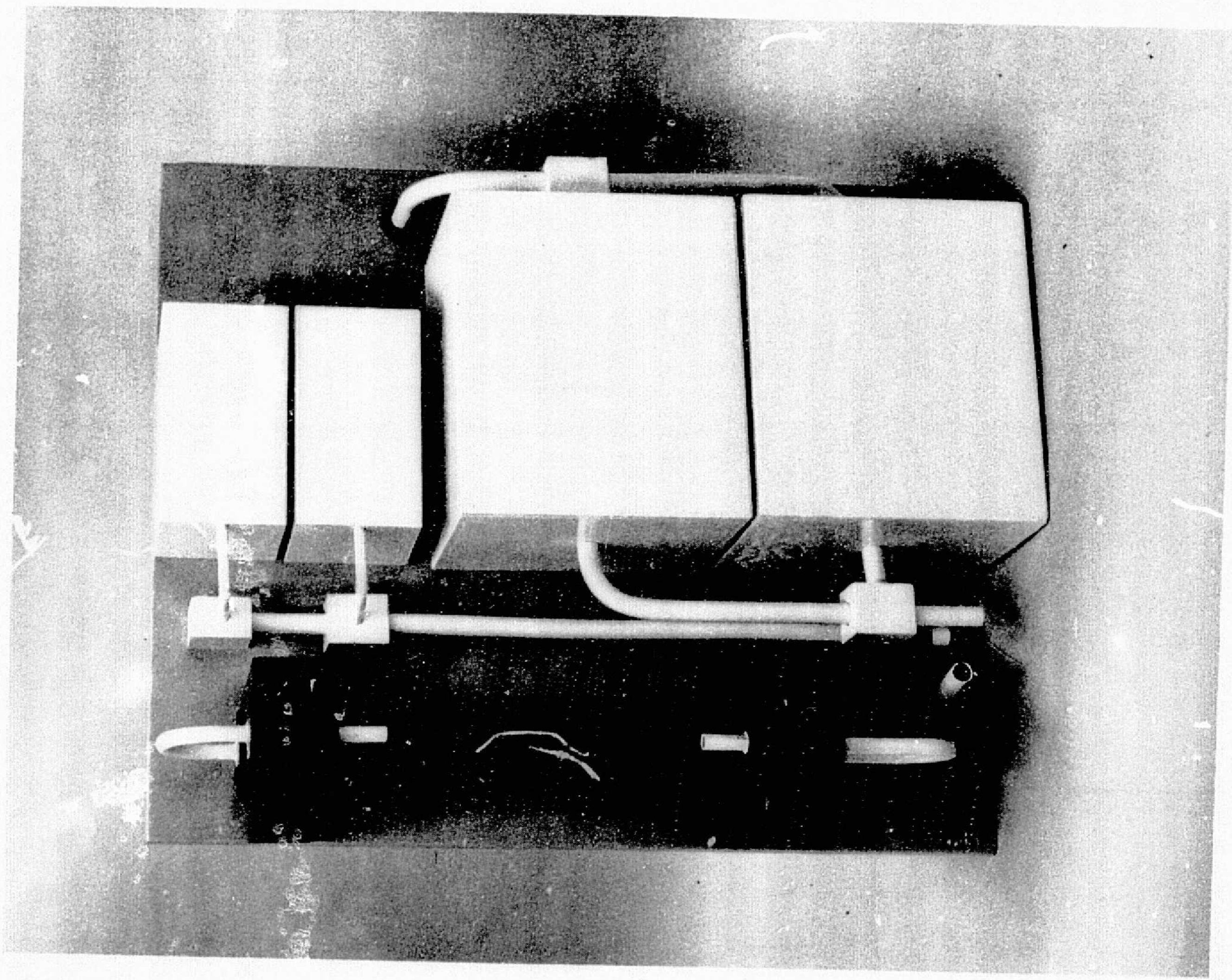
STORAGE BAG MODULE DRAWING



TRW SYSTEMS GROUP

CONSOLE SUBSYSTEM

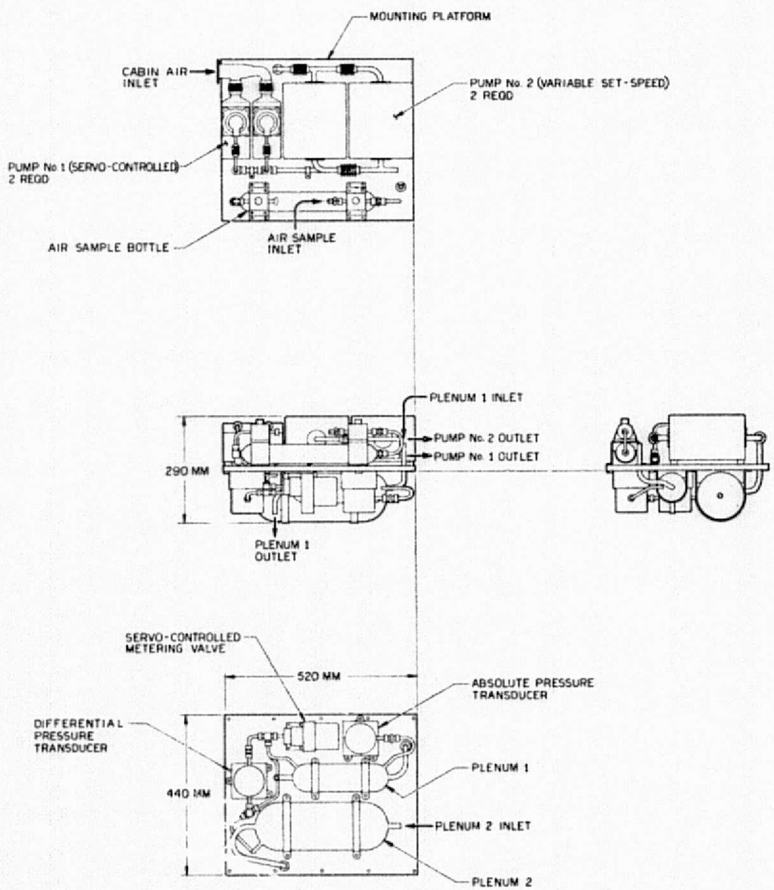
PUMP AND PLENUM MODULE MOCK-UP



TRW
SYSTEMS GROUP

CONSOLE SUBSYSTEM

PUMP AND PLENUM MODULE DRAWING

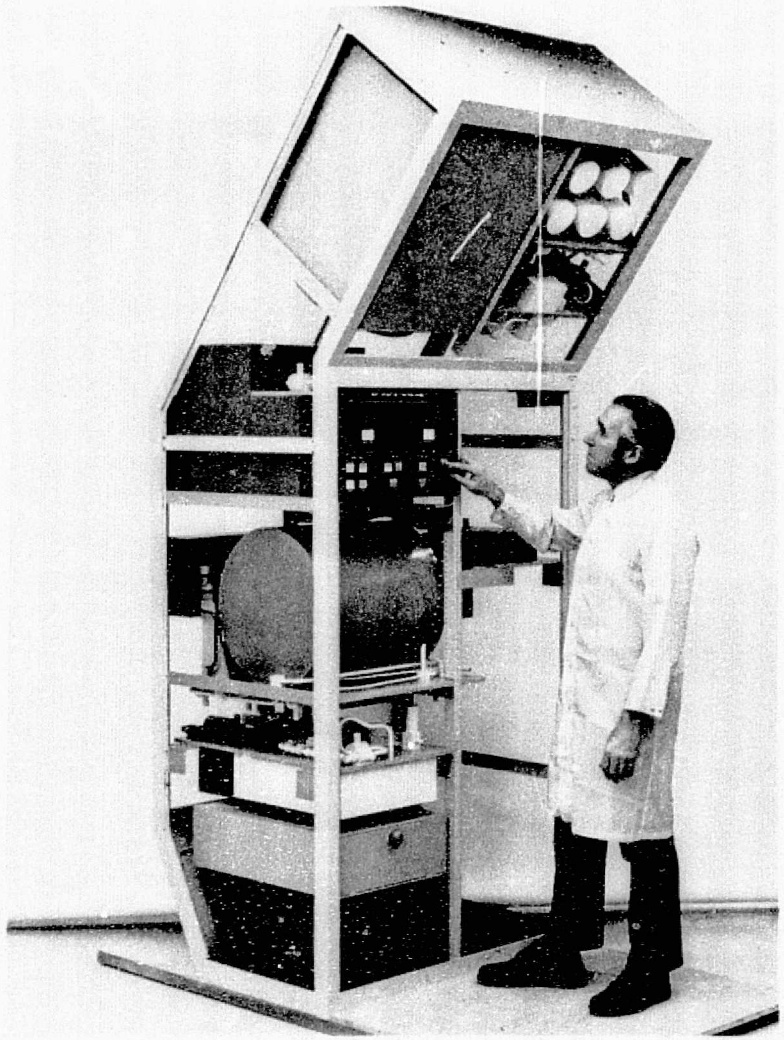


TRW
SYSTEMS GROUP

The photograph on the facing page shows TRW's partially completed full scale mock-up. The primary remaining task is completion of the plumbing interconnections between modules.

CONSOLE SUBSYSTEM

ATMOSPHERIC CLOUD PHYSICS LABORATORY MOCK-UP



TRW
SYSTEMS GROUP

The facing page is a summary of the previous discussion and highlights the principal features of the Console Subsystem.

CONSOLE SUBSYSTEM
SUMMARY

- ACPL EQUIPMENT CAN BE ACCOMMODATED IN SPACELAB STANDARD DOUBLE RACK.
- MODULAR PACKAGING CONCEPT OFFERS MANY ADVANTAGES FOR LABORATORY INTEGRATION AND TEST.
- UNREGULATED +28 VDC POWER USED WHEREVER FEASIBLE.
- COMPLETE POWER SWITCHING CAPABILITY AVAILABLE THROUGH EXPERIMENT COMPUTER.
- BENIGN SPACELAB MECHANICAL ENVIRONMENT PERMITS CONSERVATIVE DESIGN APPROACHES.

TRW SYSTEMS GROUP

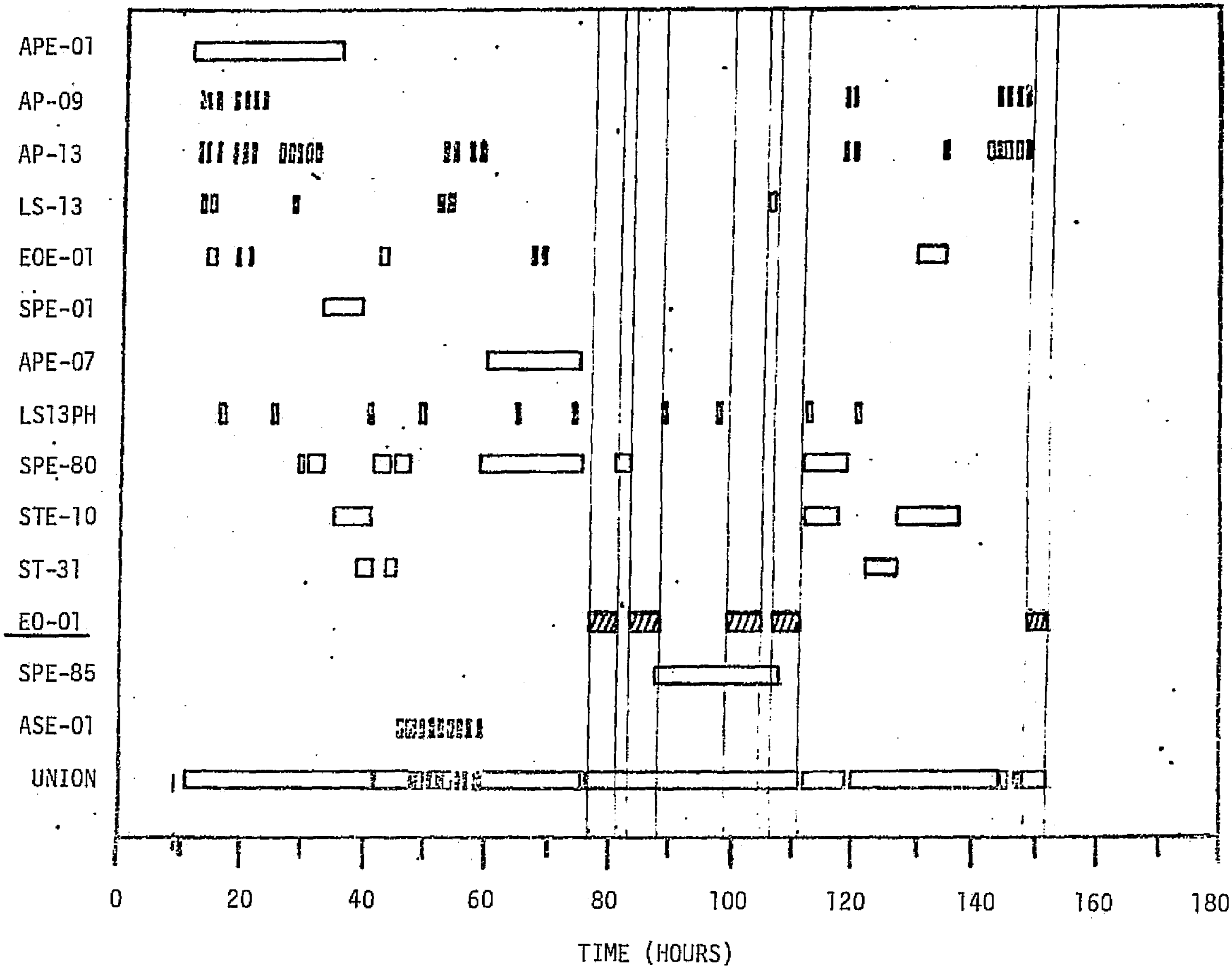
SYSTEMS SUMMARY

RALPH SCHILLING

TRW
SYSTEMS GROUP

This timeline summary is taken from the Spacelab 1 "Strawman" Summary (MSFC document SE-012-020-2H). A total of 23.7 hours of operation have been scheduled for the ACPL (payload code EO-01) in five blocks of time during the mission. For convenience in developing representative ACPL timelines, we assumed that four blocks of 5.0 hours each followed by a single block of 3.7 hours were available. The key point to be noted from this timeline is that the ACPL is the only experiment apparatus in operation during four of the five time blocks. During the third block, a European Space Processing apparatus (SPE-85) is also in operation.

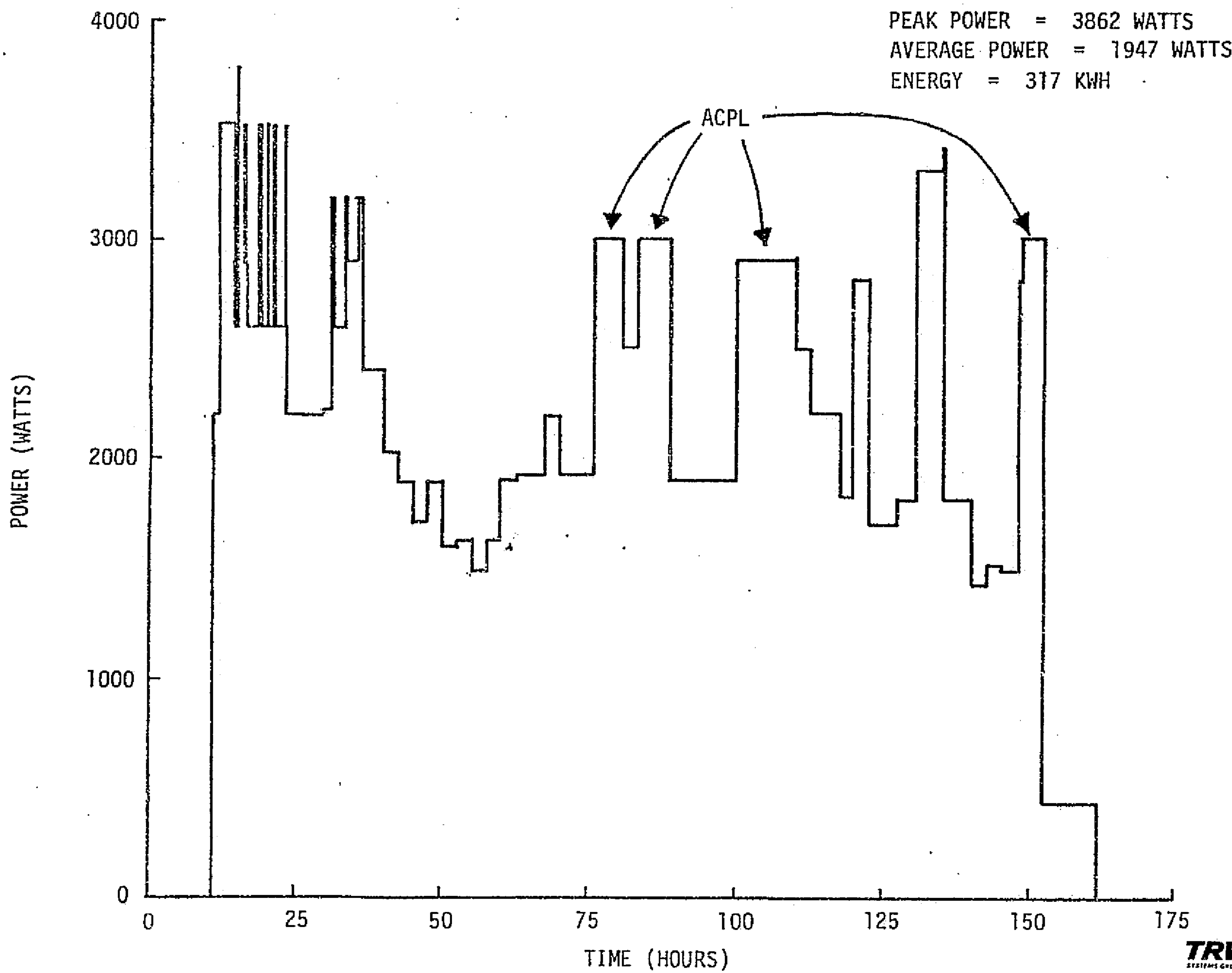
SPACELAB 1 TIMELINE SUMMARY



TRW

The power profile is also taken from the Spacelab 1 "Strawman" Summary. The main point to be noted here is that approximately 1.5 kilowatts of electrical power is available for ACPL except during the third time block. On an overall basis, 34.67 kilowatt hours of electrical energy were allocated for ACPL giving an average power of 1.46 kilowatts over the 23.7 hours. There is, however, a 27.8 percent energy overrun in the total "Strawman" energy budget.

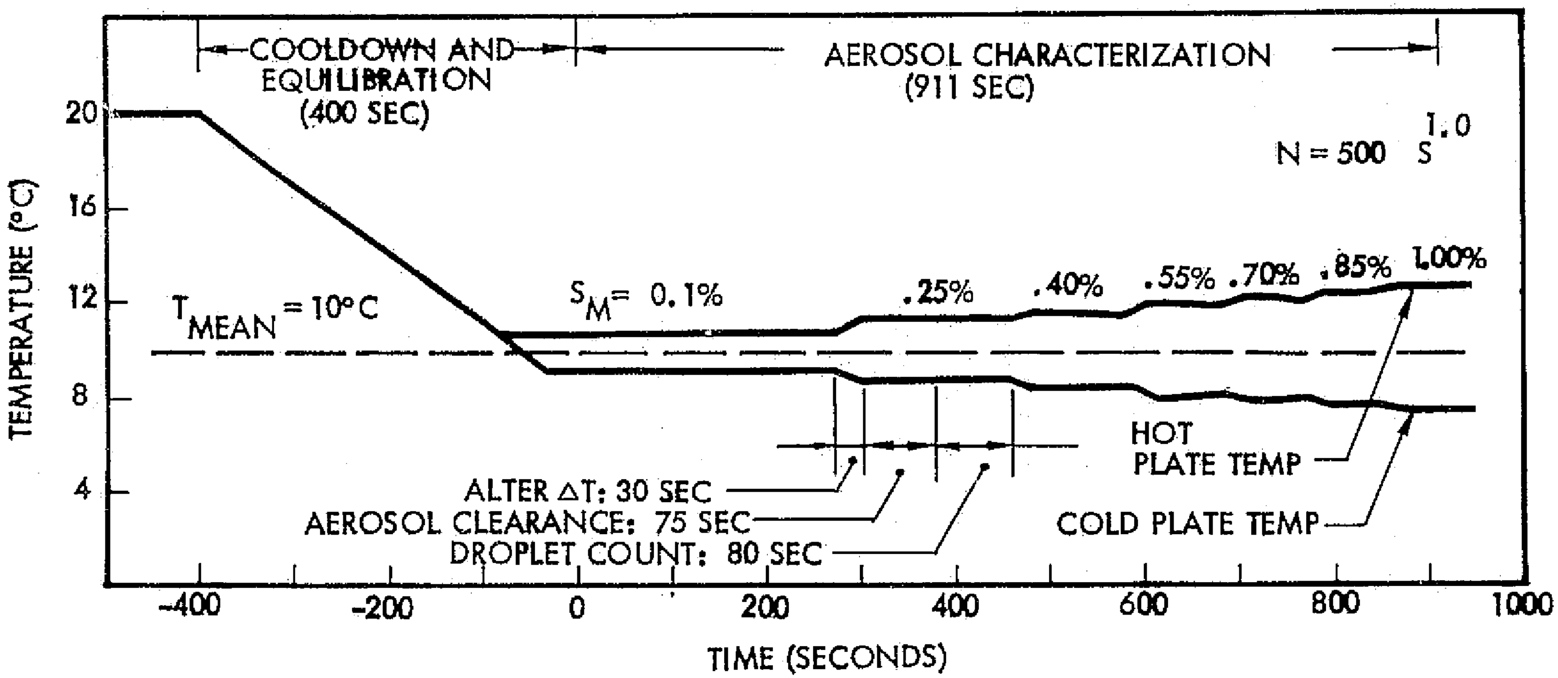
SPACELAB 1 EXPERIMENT PLUS MDE POWER PROFILE



TRW SYSTEMS GROUP

A typical timeline for a CFD chamber aerosol characterization operation is shown here. Seven steps in S_m from 0.1 percent to 1 percent were chosen to illustrate this operation. The times required to alter the plate temperature were obtained from the thermal model of the chamber. The time required to clear the previous aerosol from the chamber following each change in S_m is determined by the carrier flow. The time required to obtain 1 percent statistical error is based on a representative aerosol distribution of $N = 500\ S^{1.0}$.

TYPICAL CFD TIMELINE



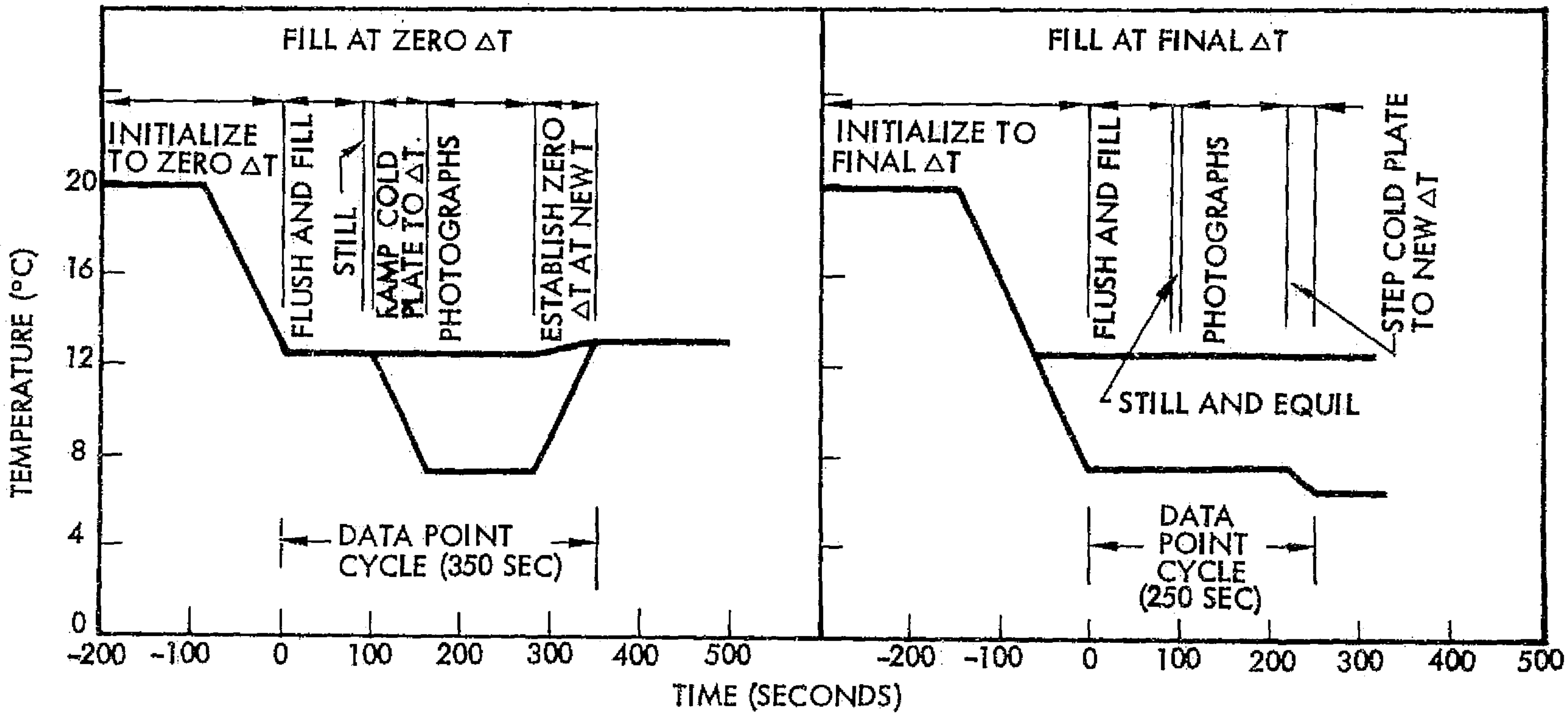
S_M (%)	CARRIER FLOW (CM^3/SEC)	TIME REQUIREMENTS (SECONDS) ALTER ΔT	CLEAR AEROSOL	COUNT 10,000 DROPS
0.1	15	INITIAL	75.0	200.0
0.25	15	30	75.0	80.0
0.40	30	30	37.5	50.0
0.55	30	30	37.5	36.4
0.70	50	30	22.5	28.6
0.85	50	30	22.5	23.5
1.00	50	30	22.5	20.0

- TOTAL CHARACTERIZATION TIME (7 POINTS) = 911 SECONDS
- BOTH PLATES STEP IN TEMPERATURE WITH CONSTANT T_{MEAN}

TRW SYSTEMS GROUP

A typical SDL chamber timeline was developed for each of the two required operating modes. The time required to change plate temperatures was derived from the transient thermal analysis for the CFD chamber. The flushing and filling time was selected to allow for ten volume exchanges.

TYPICAL SDL TIMELINES

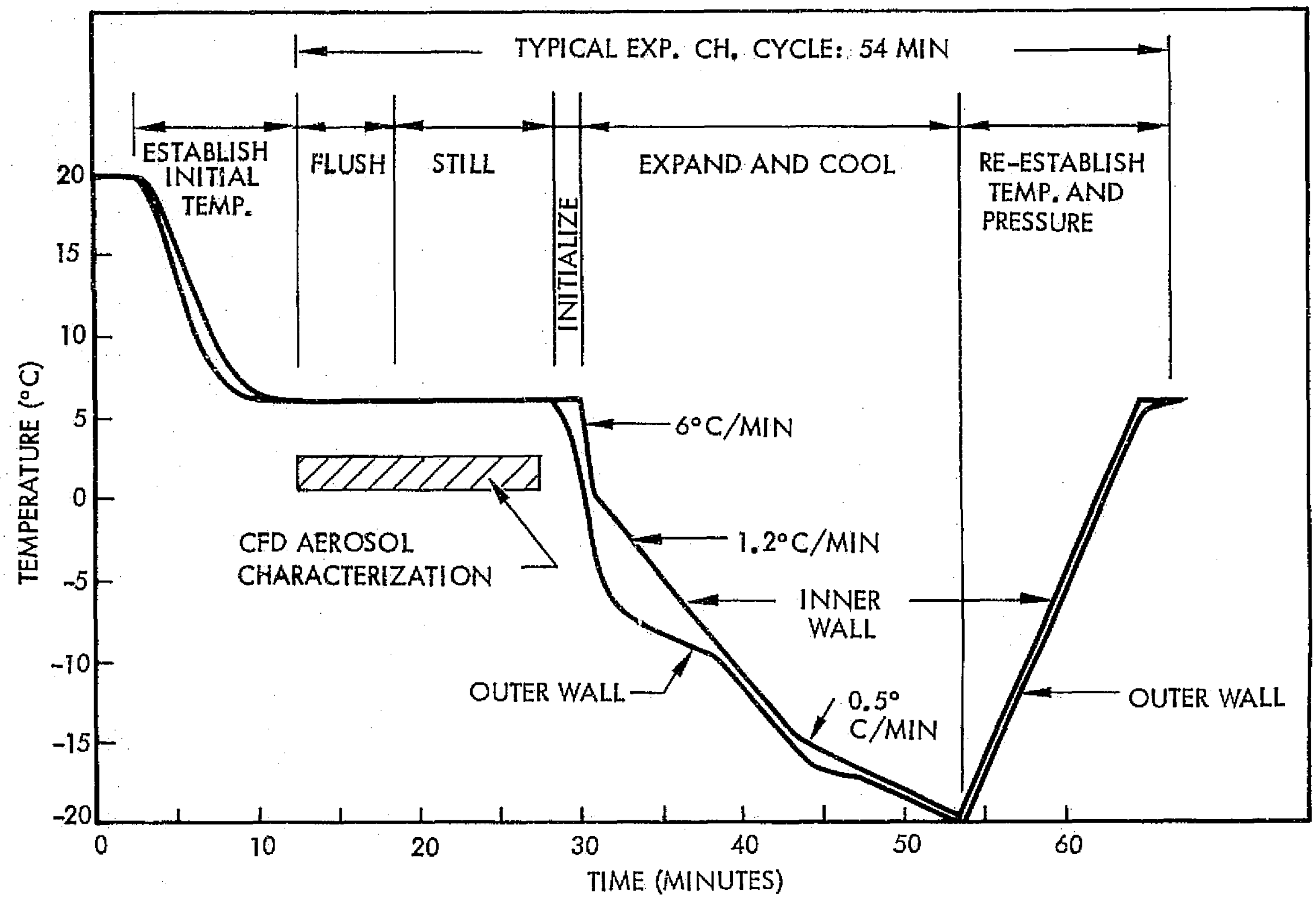


- TWO OPERATING MODES FOR SPECTROSCOPY OR DROPLET GROWTH STUDIES
  - FILL AT EQUAL PLATE TEMPERATURES AND RAMP TO FINAL ΔT
  - FILL AT FINAL ΔT
- VARIATIONS IN ΔT WITH SAMPLE IN CHAMBER ACCOMPLISHED BY LOWERING COLD PLATE TEMPERATURE TO AVOID TRANSIENT SUPERSATURATIONS
- TIME REQUIRED PER SAMPLE (DATA POINT) ≈ 250 - 350 SECONDS

TRW

The expansion chamber timeline was established to show a long-duration experiment beginning at a high cooling rate and tapering off to sustained lower rates. The flushing time allows for ten volume exchanges and the stilling period overlaps the CFD characterization cycle.

TYPICAL EXPANSION CHAMBER TIMELINE

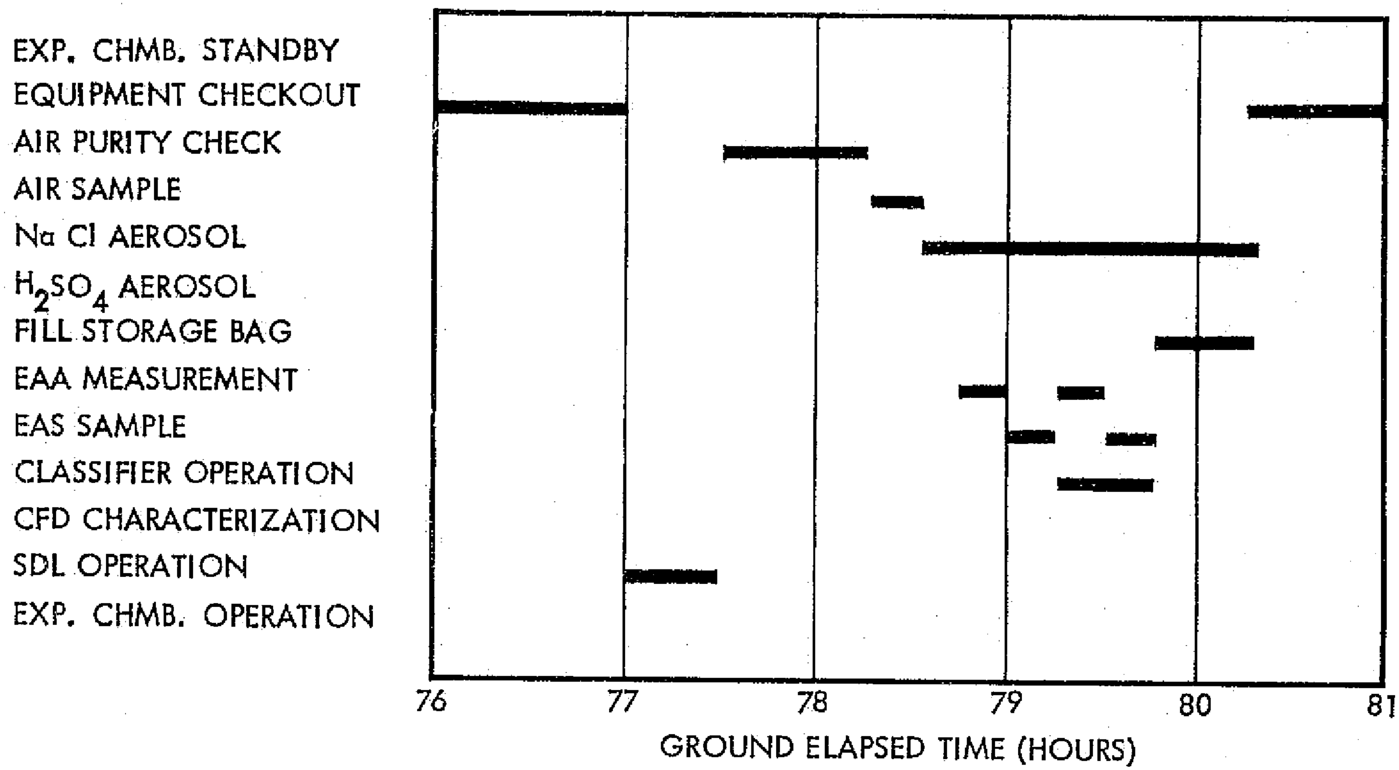


- FLUSH AND FILL AT ~ 0 ΔT BETWEEN INNER AND OUTER WALLS
- CFD CHARACTERIZATION OVERLAPS STILLING PERIOD TO ALLOW MINIMUM FLUSH PLUS STILL TIME
- TYPICAL EXPANSION CHAMBER CYCLE PERIODS: 30 – 60 MINUTES

TRW

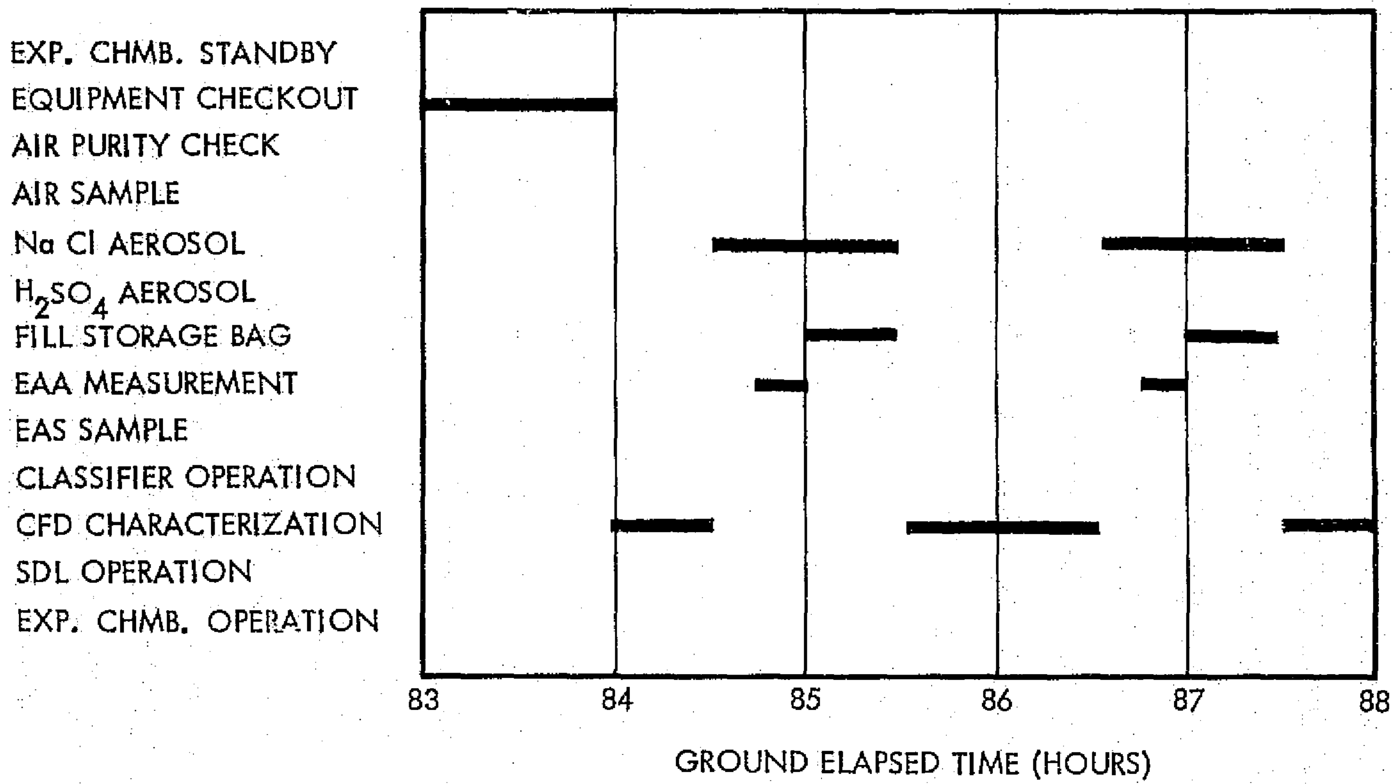
The initial time block has been primarily utilized to perform the air purity check, obtain the air sample, and check out the particle generator and counter subsystem operation. In addition, general checkout periods have been scheduled in four of the time blocks to make detailed engineering measurements.

ACPL MISSION OPERATION TIMELINE



The second time block has been utilized to check out the CFD chamber using NaCl aerosols.

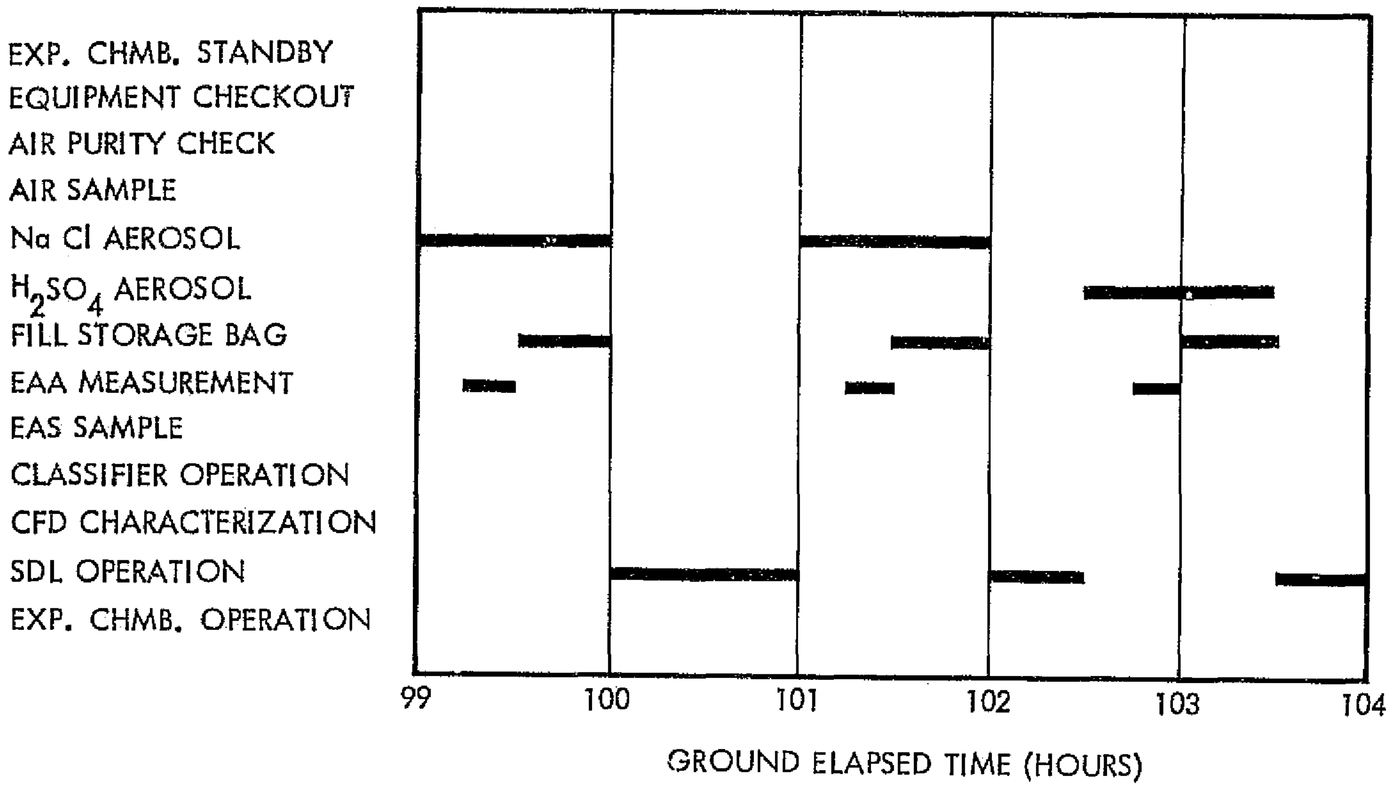
ACPL MISSION OPERATION TIMELINE



TRW SYSTEMS GROUP

The third time block has been utilized to check out the SDL chamber with NaCl aerosol. In addition, a brief check of the H_2SO_4 generator is carried out.

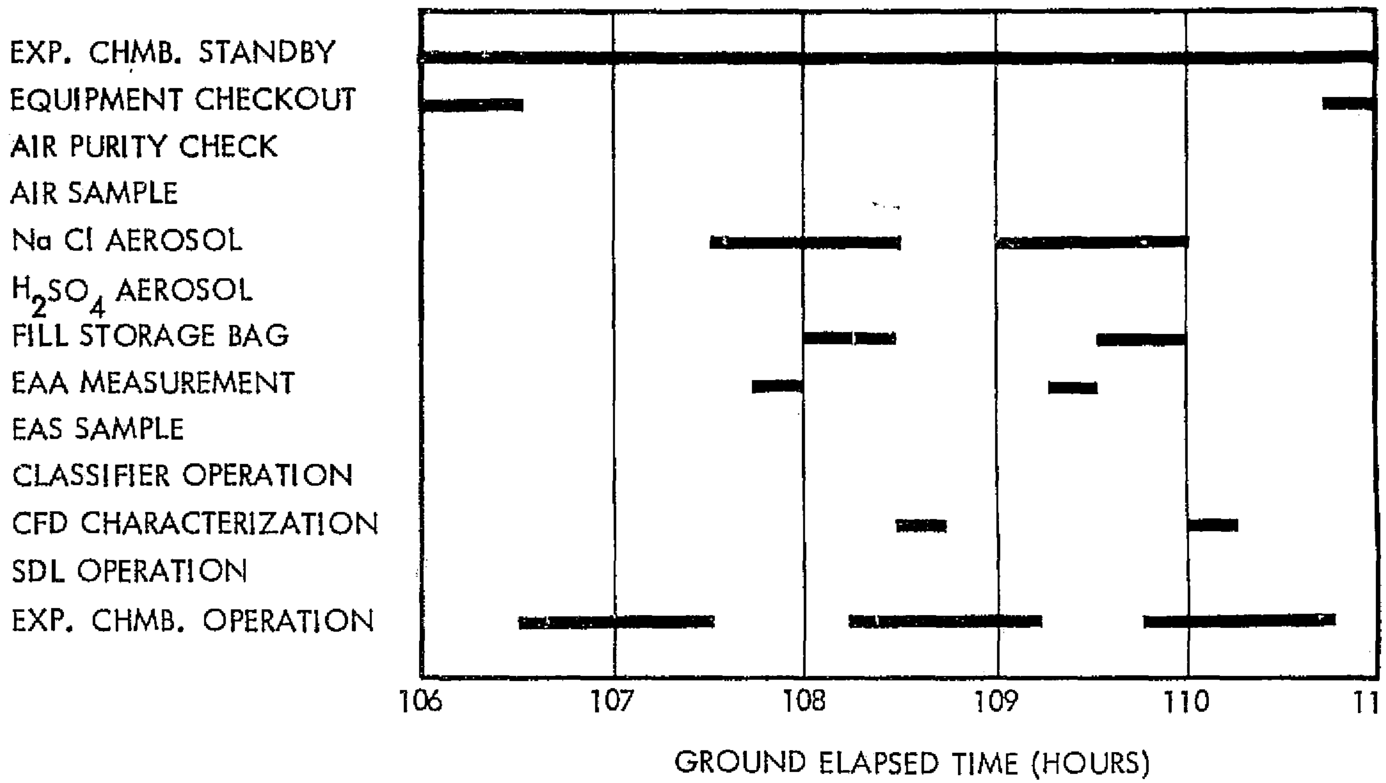
ACPL MISSION OPERATION TIMELINE



TRW
SYSTEMS GROUP

The fourth time block has been utilized to check out the expansion chamber and optical and imaging subsystem with NaCl aerosols.

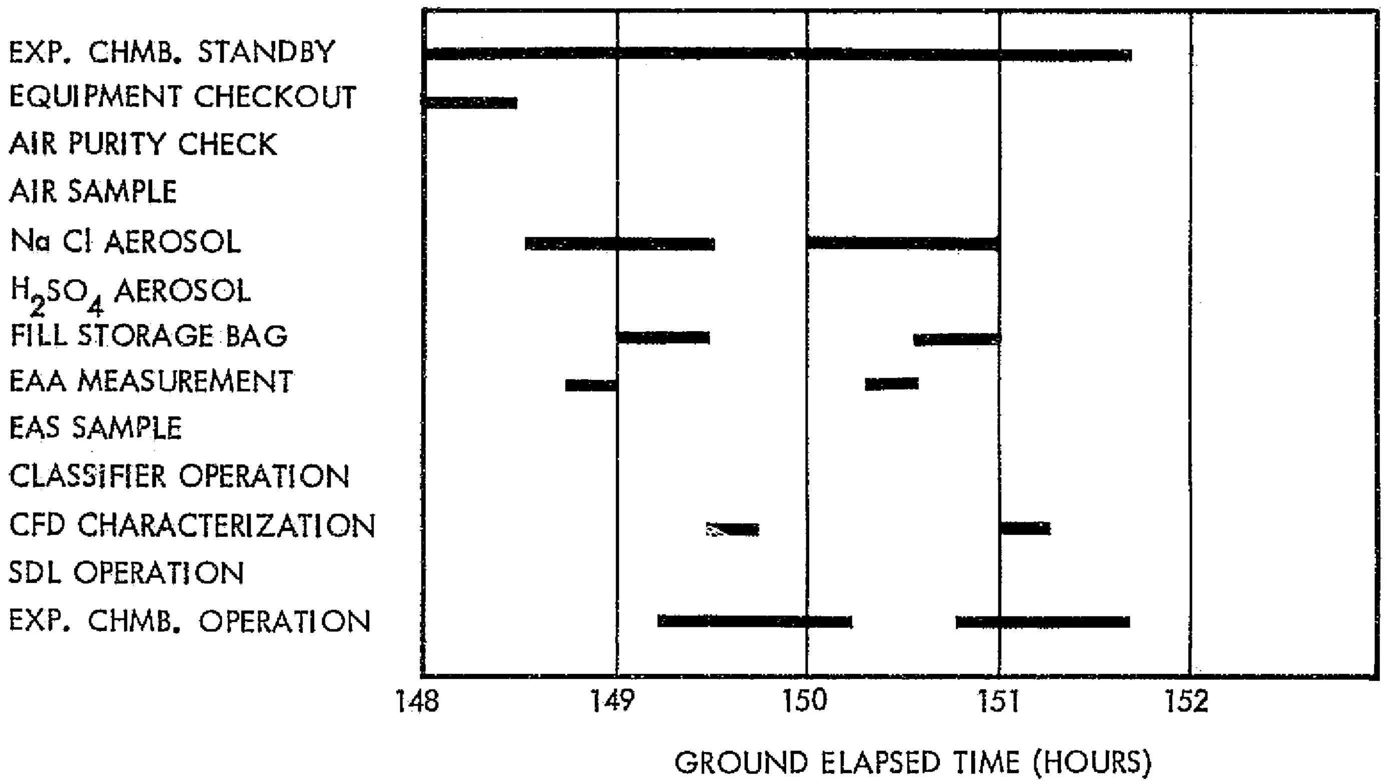
ACPL MISSION OPERATION TIMELINE



TRW

Utilization of the expansion chamber has been continued in the fifth time block.

ACPL MISSION OPERATION TIMELINE



TRW
SYSTEMS GROUP

ACPL PHASE B PROGRAM SUMMARY

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TRW
SYSTEMS GROUP

ATMOSPHERIC CLOUD PHYSICS LABORATORY

SPACELAB PAYLOAD PHASE B STUDY OBJECTIVES

- PROVIDE FINAL DEFINITION AND PRELIMINARY DESIGN OF AN INITIAL ACPL FOR FUNDAMENTAL STUDIES OF ATMOSPHERIC CLOUD MICROPHYSICAL PROCESSES IN ZERO GRAVITY.
- PREPARE PRELIMINARY PLANNING FOR DETAILED DESIGN, DEVELOPMENT, FABRICATION, TEST AND OPERATION OF THE INITIAL ACPL.
- DEVELOP REALISTIC COST ESTIMATES FOR PHASE C/D.

ATMOSPHERIC CLOUD PHYSICS LABORATORY

PRELIMINARY DESIGN STUDY ACCOMPLISHMENTS

- AIDED IN ESTABLISHING, PRIORITIZING REALISTIC SET OF SCIENTIFIC REQUIREMENTS FOR THE INITIAL ACPL.
- IDENTIFIED AND WORKED MANY KEY TECHNICAL PROBLEMS ASSOCIATED WITH MEETING THESE REQUIREMENTS.
- PROVIDED DETAILED TECHNICAL DEFINITION OF INITIAL ACPL INCLUDING IDENTIFICATION OF COMMERCIALLY AVAILABLE COMPONENTS AND REALISTIC INTERFACES WITH SPACELAB.
- DEFINED OPERATIONAL REQUIREMENTS FOR ACPL DURING INTEGRATION WITH SPACELAB AND DURING THE INITIAL MISSION.
- DEFINED REALISTIC PHASE C/D PROGRAM REQUIREMENTS FOR FABRICATION AND OPERATION OF THE INITIAL ACPL. DEVELOPED A PLAN FOR ACCOMPLISHING THESE REQUIREMENTS.

TRW
SYSTEMS GROUP